D180-15082-1

DEGRADATION OF LEARNED SKILLS

Effectiveness of Practice Methods on Visual Approach and Landing Skill Retention

by

Thomas E. Sitterley
Lawrence P. Zaitzeff
and
Wayne A. Berge

October 1972

Prepared under Contract No. NAS9-10962

THE BOEING COMPANY
Seattle, Washington

for

Manned Spacecraft Center
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ABSTRACT

Flight control and procedural task skill degradation, and the effectiveness of retraining methods were evaluated for a simulated space vehicle approach and landing under instrument and visual flight conditions. Fifteen experienced pilots were trained and then tested after 4 months either without the benefits of practice or with static rehearsal (checklists and briefings), dynamic rehearsal (briefings and video taped flight presentations), or with dynamic warmup practice (closed loop simulator practice). Performance on both the flight control and procedure tasks degraded significantly after 4 months. The rehearsal methods effectively countered procedure task skill degradation, while dynamic rehearsal or a combination of static rehearsal and dynamic warmup practice was required for the flight control tasks. The quality of the retraining methods appeared to be primarily dependent on the efficiency of visual cue reinforcement.

FOREWORD

This report summarizes an experimental study accomplished as the third part of a program designed to investigate the degradation of learned skills as applicable to spaceflight tasks. The research reported here was begun in July 1971 and was completed in August 1972 for the NASA Manned Spacecraft Center under Contract NAS9-10962. The study was initiated by Dr. William E. Fedderson, Chief of the Behavioral Laboratory, Biomedical Laboratories Division. Dr. Fedderson was the NASA Project Monitor throughout the study.

The Boeing Program Manager was Dr. George D. Greer, Jr. and the Principal Investigator was Dr. Thomas E. Sitterley. The authors gratefully acknowledge the extensive assistance of Mr. Gale M. Rhoades who contributed to simulator modification, operation, and data reduction, to Messrs. David Tubb, Louis Hough and Douglas Berg for their contribution in math modeling, computer programming and flight simulator operations, and to Mr. Allen Fukushima for his engineering assistance in terrain model and visual systems modification and operation.

The first part of this investigation of degradation of learned skills was covered in Report D180-15080-1, Degradation of Learned Skills - A review and Annotated Bibliography. The second part was covered in Report D180-15081-1, Degradation of Learned Skills - Effectiveness of Practice Methods on Simulated Space Flight Skill Retention.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

APPENDIX

LIST OF FIGURES

LIST OF TABLES

APPENDIX

1. INTRODUCTION

The ability of pilots to maintain flight control skills over periods of operational inactivity has long been of considerable concern. Practical experience and reviews of many years of research (Naylor and Briggs, 1961; Gardlin and Sitterley, 1972) graphically demonstrate the susceptibility of skilled task performance to degrade with the passage of time. However, not all of the data or experiences fit this generalization. Much of the conflict apparently occurs because many studies or observations, presumably directed toward the same question, look at completely different tasks, performed by dissimilar subject populations, and measured against desparate performance criteria.

Particularly critical are the task characteristics and specification of performance criteria. When carefully defined and compared, an apparent superiority in skill retention is found for continuous control tasks as opposed to procedural tasks. Similarly, the relative benefits of the same amount and type of practice are generally greater for procedural tasks as compared to continuous control tasks. Naylor and Briggs (1961) suggested that the primary difference between the two types was largely a question of organization. Typically the procedural task is held together with less spatial or temporal continuity whereas each element of the continuous control task relates to the previous element and suggests or reinforces the succeeding element.

While useful from the standpoint of task description, the procedure task/continuous control task dichotomy can lead not only to an incorrect prediction of the retention of flight skills but also an inappropriate specification of retraining methods. As pointed out by Sitterley and Berge (1972), piloting an aircraft, while primarily psychomotor in nature, requires a significant cognitive contribution in terms of information integration and decision making. Cognitive, discrete, and continuous control task elements are represented in the flight control task and these same elements are found in varying degree as part of procedural task performance. The Sitterley and Berge study graphically demonstrated the requirement to understand the relationship of these elements to the total task in terms of the defined measures of performance.

In that study, subjects were trained to manually control a simulated space vehicle from launch through orbit insertion. Flight performance was evaluated by measures of integrated pitch and altitude error from the desired flight profile and discrete measures of altitude and rate errors at orbit insertion. Throughout the flight, emergency procedure performance was measured in terms of time and error. The effects of no practice, rehersal practice, and warmup practice on skill retention were factorially evaluated over retention intervals from 1 to 6 months.

The contention that the rate and magnitude of performance degradation was not only a function of time and type of training, but also closely related to the performance measurements, was substantiated. Interpreted in relation to each other, the performance measures indicated that the procedure task degraded more consistently and to a greater degree than the flight control task, and while static rehersal effectively countered procedural degradation, some form of dynamic warmup appeared necessary for flight control skill retention. However, for both tasks, the various performance measures sampled task elements across the continuum from cognitive decision making to discrete and continuous psychomotor control. As such, each measure taken by itself could have resulted in different conclusions as a function of the task element sampled.

While the Sitterley and Berge study assessed flight control and procedural skills, it did not address one of the critical elements of pilot performance: far-field vision and perceptual cues. The requirement for far-field (out-the-window) visual perception is an inherent part of the landing. Far-field visual perception has been long recognized as one of the most critical aspects of airplane flight, and emphasized, of course, in its relation to a successful approach and landing. However, surprisingly little is known about when far-field visual tasks can be expected to deteriorate beyond the point of acceptability.

Certainly, the complex perceptual cues and additional burden of integrating the visual information with the flight task would suggest that the approach and landing task would be subject to greater skill degradation than that found by Sitterley and Berge. Further the operational tasks should be more complex in terms of the perceptual/motor coordination, timing, and task load. Therefore, even with experienced pilots, the previous data would suggest a no-practice limit of 3 months or less is required to preserve acceptable flight skills. This estimate fits quite closely to common naval aviation procedure of requiring carrier landing practice at least once a month to preserve the perceptual coordination and timing.

The next question is how to counter visual flight control skill degradation. Dynamic closed-loop flight trainers with elaborate visual simulation attachments are currently available. The use of these trainers in conjunction with actual flight has proven to be a cost effective approach for initial pilot training. However, after a pilot has reached a high level of proficiency and experience, it is unknown if this level of trainer sophistication is required for periodic retraining, or if other methods might suffice. It is true that simulator based training is less expensive than actual flight training, and frequently provides the only available method for training. Nevertheless, training simulators are still very expensive to obtain and operate. Further, many circumstances of cost, geographic, and space/weight/power restrictions limit the use or availability of simulators to provide flight skill practice during extended periods of flight inactivity.

Purpose

Using a visual flight simulator, experienced pilots, and an operationally oriented flight task, the purpose of this study was: a) to quantify the magnitude of degradation of flight control tasks which involve the use of far-point (out-the-window) visual cues; b) to investigate the retraining effectiveness of non-simulator static rehersal and open-loop dynamic display practice in comparison to dynamic closed-loop warmup practice; and c) to evaluate these skill retention methods for normal and emergency mode procedures under conditions of high task load.

2. METHOD

Experienced pilots were trained to fly a simulated spacecraft of the H-33 Space Shuttle orbiter configuration through an approach and landing. Flight control and procedural performance was measured at the end of training and again at the end of four months with and without the benefits of practice.

Subjects

Fifteen experienced pilots currently not flying were used in this study. In order to reduce the amount of initial training required and to increase the uniformity and representativeness of the subject population, the pilots were obtained from Boeing engineering and technical staff groups. The group was a mixture of flight test engineers, control systems personnel, training requirements staff, and crew systems engineers.

The subject population was required to meet the following criteria: (1) previous formal flight training and experience as a pilot; (2) commitment to no flight activities during the test period; (3) vision, 20/30, corrected; and (4) under 55 years of age.

The average age of the pilot population was 44.4 years with a range of from 33 to 50. The experience level of the subjects averaged 5,300 pilot hours with a range of from 900 to 12,600 hours. They averaged 1,250 instrument hours with a range of from 100 to 5,000 hours. The pilots averaged 5.3 years since their last flight; the most current had been flying up to within 6 months before the start of the test; one of the group had not flown for 16 years.

Task Description

The pilots task was to control the vehicle from an altitude of 31,000 feet through a descending turn to an approach and landing on a runway. Figure 1 depicts a schematic of the basic flight profile which required approximately 6 min. 45 sec. to complete. The detailed mission description, approach data, and charts are presented in the appendix. Basically, the flight profile assumed that the pilot has just made a successful de-orbit and reentry pass through the transition stage.

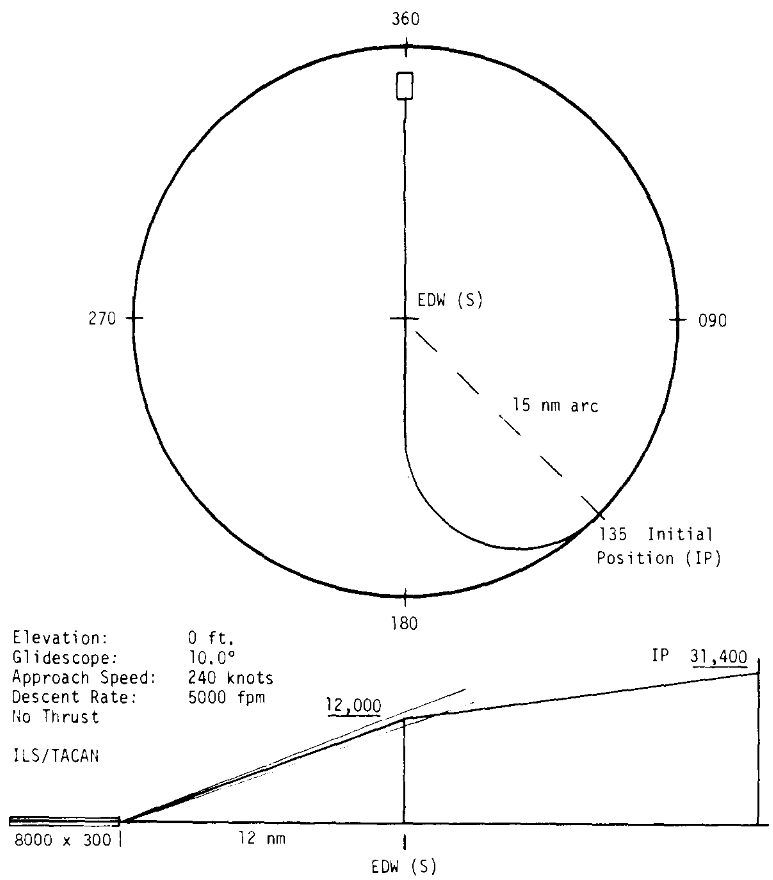


Figure 1: Flight Schematic-Edwards AFB (SIM) Simulation Approach, H-33 Orbiter

The test mission began at 31,400 feet, 15 nautical miles from a simulated Edwards TACAN. The approach and landing were made unpowered. Ceiling was 10,000 feet, overcast, visibility 15 miles; the cloud deck was solid through 35,000 feet. A turning approach descending at about 5,000 feet per minute was made to the TACAN using instruments only (IFR). Energy management was accomplished through judicious use of speed boards at an equivalent airspeed of 240 knots. Stabilization on the localizer and glideslope provided a straight-in approach to the Edwards runway 12 miles from the TACAN. During this portion of the flight, the pilot was required to perform emergency procedures to correct a series of malfunctions in the vehicle's flight control system (SAS Failure Procedure).

After crossing the TACAN station, a complete electrical power failure occurred. At this time, the pilot was required to perform a corrective procedure (Subsystem Scan). During the failure, the vehicle was repositioned to one of a standardized set of offsets from the flight path. These offsets, presented in random order, permited the evaluation of the final visual approach performance from a known starting point for all pilots. Upon power recovery (in 12 seconds), the pilot continued the descent on instruments through 10,000 feet, applying corrective control inputs to return the vehicle to the desired flight path.

At this point, the pilot broke out visually and was able to use the combination of instruments and external visual environment in establishing the required lineup and glideslope. At 8,000 ft, the on-board terminal navigation system failed, and the pilot was required to perform another subsystem scan corrective procedure. No correction of the failure was possible, forcing the pilot to make the remaining approach and final touchdown under visual conditions (VFR) with only basic vehicle attitude, speed, and altitude information.

Equipment

The experimental test was conducted using the simulation facilities of the Boeing Aerospace Group in Seattle. The simulation equipment was comprised of four major parts: (a) cockpit with associated displays and controls, (b) visual simulation system, (c) computer and simulation control system, and (d) the procedure task function logic system. The equipment and associated computer software was integrated to provide a highly realistic simulation of a fully aerodynamic Space Shuttle orbiter descent, approach and landing as controlled visually and by instruments from a one-man cockpit.

Cockpit

A one-man cockpit, configured with all displays and controls required to fly the simulated mission was used for both pilot training and retention testing. The cockpit, used for general purpose part-task simulation studies, was reconfigured for this experiment. No attempt was made to duplicate any Space Shuttle cockpit concepts. Figure 2 shows the general cockpit display/control configuration in relation to a simulation pilot.

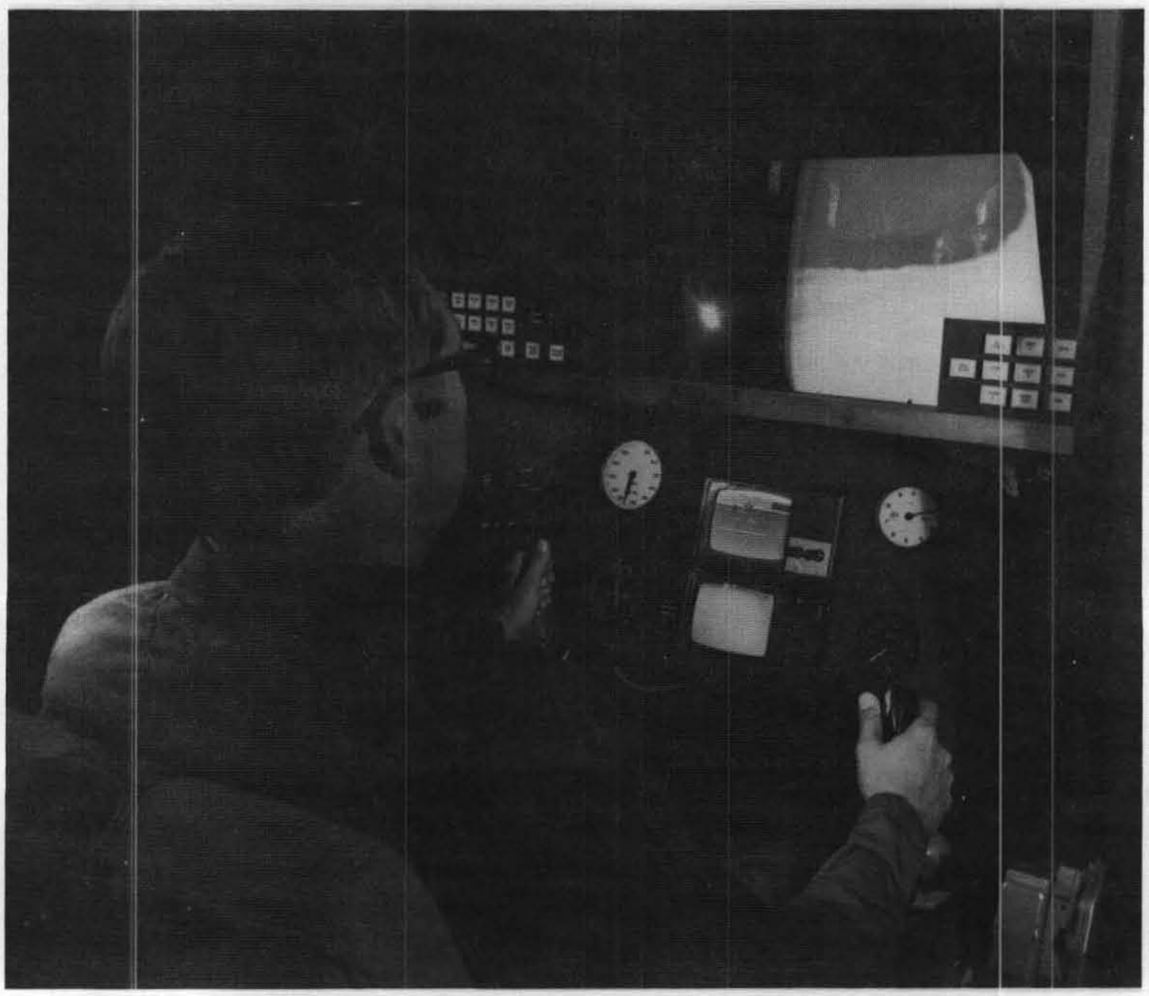


Figure 2: Simulation Cockpit with Pilot

External out-the-window visual scenes were simulated using a 21-inch cathode ray tube. This 1029 line television display was viewed through a set of acrylic lenses which produced the visual image at optical infinity. This infinity optics system provided a field of view of approximately 40 degrees through a centrally located windscreen.

A detailed description of the cockpit, all displays and controls and their function and use is described in the Flight Control and Procedure Training Package contained in the appendix. Basically, the displays included electromechanical and cathode ray tube displays for attitude, velocity, altitude, course, and status information. An X-20 type, two-axis, sidearm controller provided proportional rate commands for pitch and roll. Rudder pedals provided displacement commands for yaw. Pitch trim and speedboard commands were provided through discrete rate controls.

Visual Simulation System

The external environment seen by the pilot through the electro-optical windscreen display was produced by the Boeing visual flight simulator. This simulation system made use of high resolution television cameras, computer controlled to fly over terrain models. The high resolution closed circuit television system consisted of cameras mounted on two precision 6 degree freedom television camera/servo systems. The video signals were fed through a special effects/video mixing control to the 1029 line TV monitor in the cockpit.

The 1 inch vidicon cameras operated with a 1029 line standard. Horizontal resolution was 700 television lines and vertical resolution was 650 television lines. Scanning linearity was 1.5 percent across the field of view. Each camera was mounted on a rail guided carriage and gimbal system. The computer controlled carriages and gimbals were digitally positioned in front of the two terrain models. Precision control was maintained with both positional and velocity feedback signals to an accuracy of 0.001 in. in translation and 3 minutes of arc in rotation.

Two scale relief terrain models were used during the visual portion approach. These models provided a realistic view of a modified approach to Edwards AFB from an altitude of 10,000 ft to touchdown. An arbitrary runway heading of 360° was used, with the runway scaled to the dimensions of 200 x 10,000 feet. Figure 3 depicts Model II of Edwards AFB and one camera/servo system carriage. This model was 11 ft x 24 ft (Scale 1:6250) and provided terrain feature representation to a vehicle altitude of 175 ft. Figure 4 depicts the camera eye view of Model II, approximately 5 miles from the runway threshold.

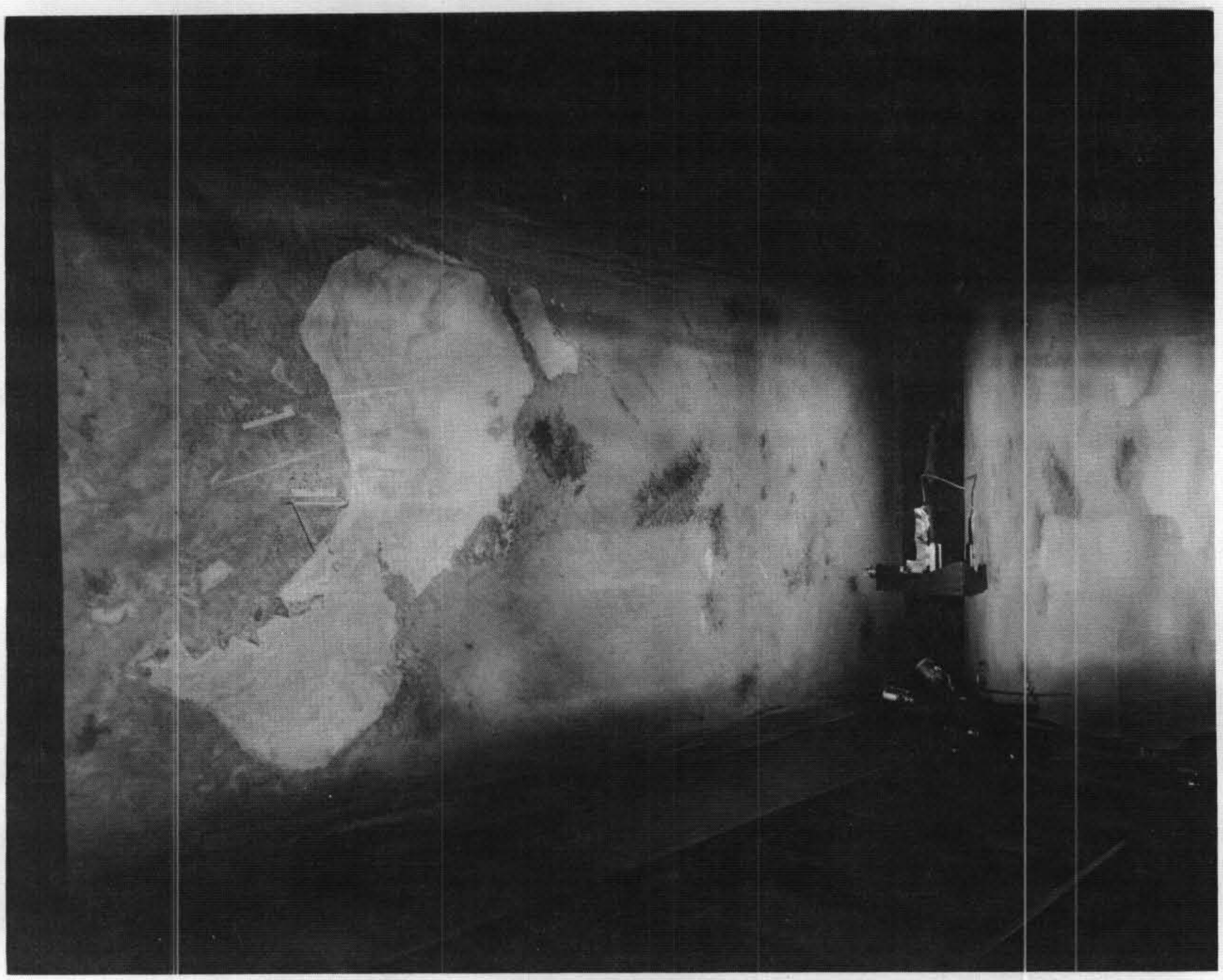


Figure 3: Terrain Model II - Edwards AFB, with Camera Stage and Lighting Mirror

Figure 4: Camera View of Approach, Approximately 5 Miles from Threshold

Model I provided the detailed representation of the runway for pilot's eye altitudes of 300 ft to 20 ft (Scale 1:200). This 11 ft by 90 ft model is depicted in Figure 5 along with its camera/servo system. During pilot training and performance testing, the Model I approach lights and adjacent terrain were replaced with dry lake bed features, scaled and contrast matched to Model II.

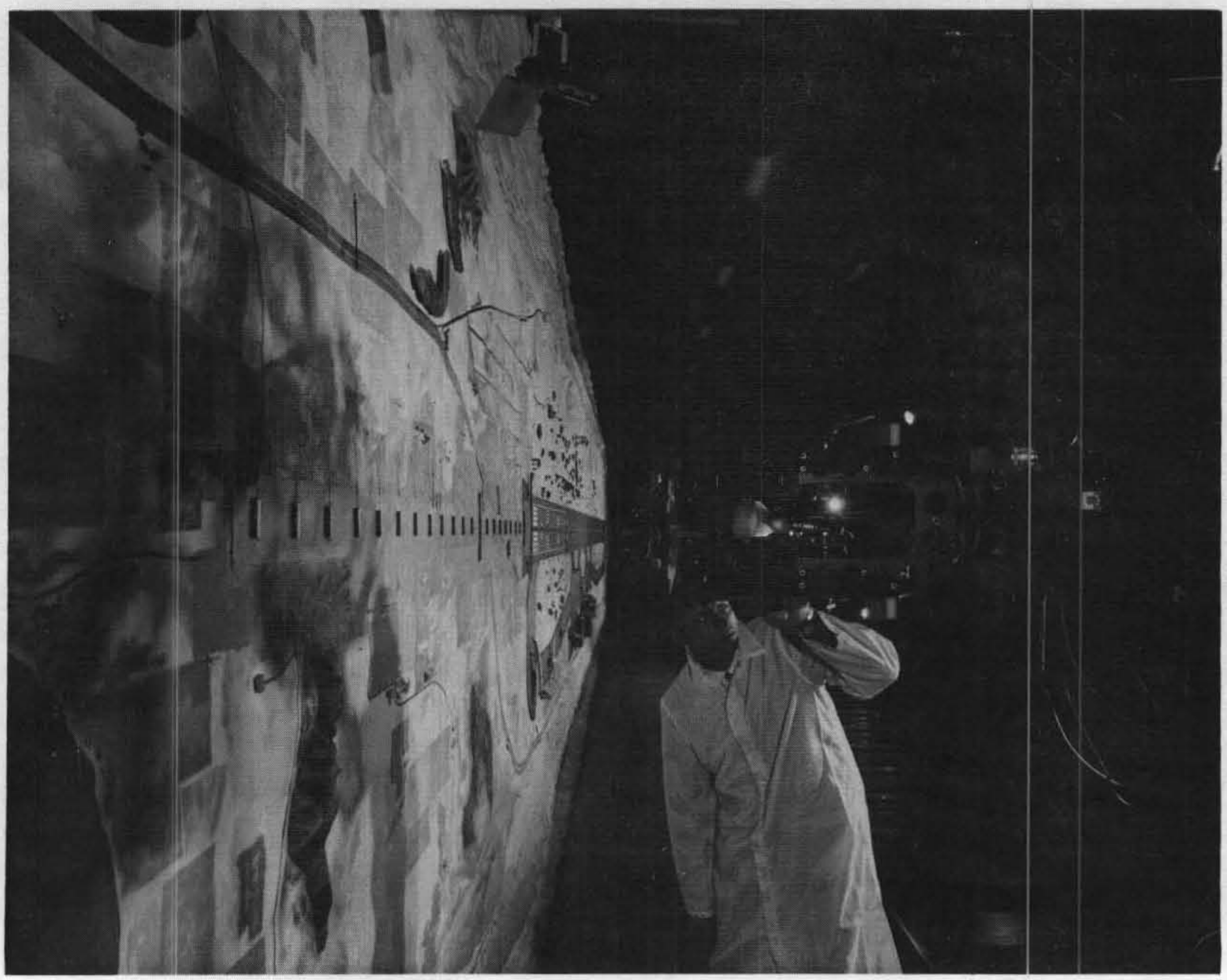


Figure 5: Terrain Model I - Runway, and Camera/Servo System

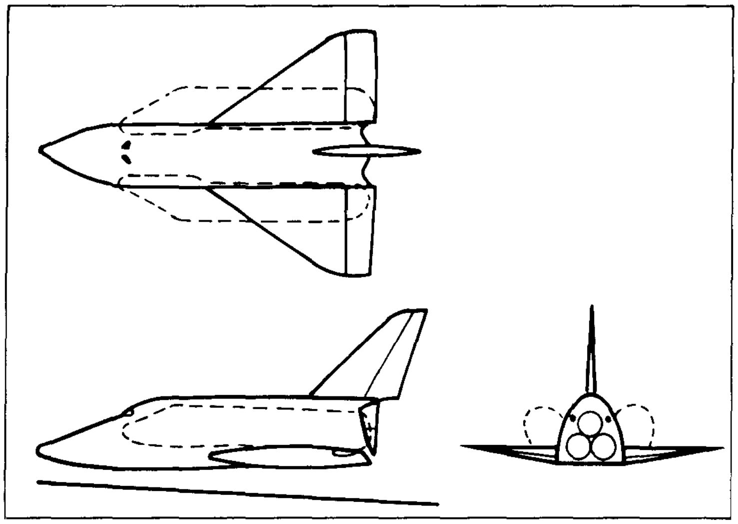
The visual transition between the two models occurred when the vehicle passed through an altitude of 300 ft. The landing model camera stage was set in motion by the computer while the other camera stage was still flying. After the camera was synchronized with the vehicle's flight, the visual transition was accomplished by computer controlled video fade-in/fade-out of the two TV camera/terrain model systems. The visual image transition between the two terrain model runways was subjectively evaluated by both Boeing and NASA personnel as very good.

Computer System

Simulation of the flight vehicle aerodynamics, flight control and cockpit information display, and visual simulation system control were accomplished using a portion of the Boeing Visual Flight Simulator computer system. One XDS 930 digital computer was operated in conjunction with a Varian 622i digital computer, a Sanders ADDS 900 graphics display system, and analog to digital and digital to analog conversion equipment.

The mathematical model which described the dynamic flight of the H-33 orbiter vehicle and the flight environment was programmed for real time solution on the main digital computer. The model was a relatively sophisticated description of the vehicle, including computation of the aerodynamic forces and moments, body axis/stability transformations, translation and rotational accelerations and velocities, and dynamic pressures as well as longitudinal landing gear dynamics, aerosurface and speedbrake dynamic pressures, stability augmentation system and flight control system operation. Included in the model were computations for the flight environment in terms of wind accelerations, velocities, shear, and gusts. Figure 6 depicts the general characteristics of the H-33 vehicle.

Input commands from the pilot in the cockpit and programmed environmental conditions were used to compute the vehicle attitude, position and velocity information. This information was sent as operation commands to each axis of the visual simulator camera servo system, which oriented the high resolution TV cameras over the scaled terrain models. The resulting video signal was then processed and fed to the large high resolution TV display in the cockpit. The motions of the visual scene corresponded to what would be seen through the cockpit window. Simultaneously, vehicle attitude, position, and movement data was processed for display on the cockpit instruments.



		TOTAL VEH	BODY
LENGTH	FT	157	135
WIDTH	FT	95	25
HEIGHT	FT	61	27.5
LANDED WEIGHT	LB	240,000	–
FIXED SURFACES		WING	FIN
AREA EXPOSED	SQ FT	2,900	855
CHORD–AT FUS	FT	68	36.7
AT TIP	FT	15.5	14.7
SWEEP–LE	DEG	55	47
TE	DEG	-5	21.8
ASPECT RATIO		1.846	1.33
TAPER RATIO		0.178	0.38
DIHEDRAL	DEG	5	–
CONTROL SURFACES		ELEVONS–TOTAL	RUDDER–TOTAL
AREA TO HINGE LINE	SQ FT	820	292
CHORD–ROOT	FT	13.6	12.8
TIP	FT	10.0	4.9
SPAN (EACH)	FT	34.8	34.8

Figure 6: H-33 Space Shuttle Orbiter General Characteristics

Throughout each simulation flight, the specified flight performance data was collected and stored. At the end of each flight, the 32 flight performance measures were printed along with pilot's names, session and flight numbers, and corresponding experimental conditions. After each set of five flights, block summary data and standard deviations were printed.

Procedure Task Function Logic System

The procedure task function logic system (PTFLS) simulated subsystem failures and operated the procedure task displays and controls. Subsystem failures programmed on the PTFLS were initiated both manually and by computer control. As a function of pilot responses to the programmed failures, the PTFLS sequenced through the procedure logic, providing subsystem status information to the pilot on the cockpit displays. In response to pilot selection of primary or alternate stability augmentation system (SAS) elements, the PTFLS transmitted command signals to the computer system to fail or reinstate the SAS program for one or all vehicle axes. PTFLS command signals likewise directed computer programs to initiate auxillary power and terminal navigation failures. Procedure task time and error data was recorded on the PTFLS FM magnetic tape for subsequent data analysis.

Procedure

The experimental procedure was broken down into three general phases. The first phase was the initial briefing and training of the pilot test subjects to perform the flight control and procedure task. This phase concluded with qualification testing of the pilots. The second phase was the retention interval. During this 4-month period of the subject's absence from the simulated space mission and normal flying, training performance data analysis was completed so as to permit assignment of the subjects to separate groups of comparable overall ability. The third phase involved applying the specific refresher procedure as established and assigned to each group and carrying out the retention testing of the subject population.

Initial Training

The initial training involved an introduction to the problem, groundschool, and then the comprehensive training. Throughout training, each pilot had a complete mission description, flight control and procedure training handbook (Appendix). Each pilot received his training in a series of 1 hour and 2-1/2 hour training sessions over a 5-day period of time. Figure 7 depicts the training schedule flow that was used to bring the pilots to their qualification level of performance.

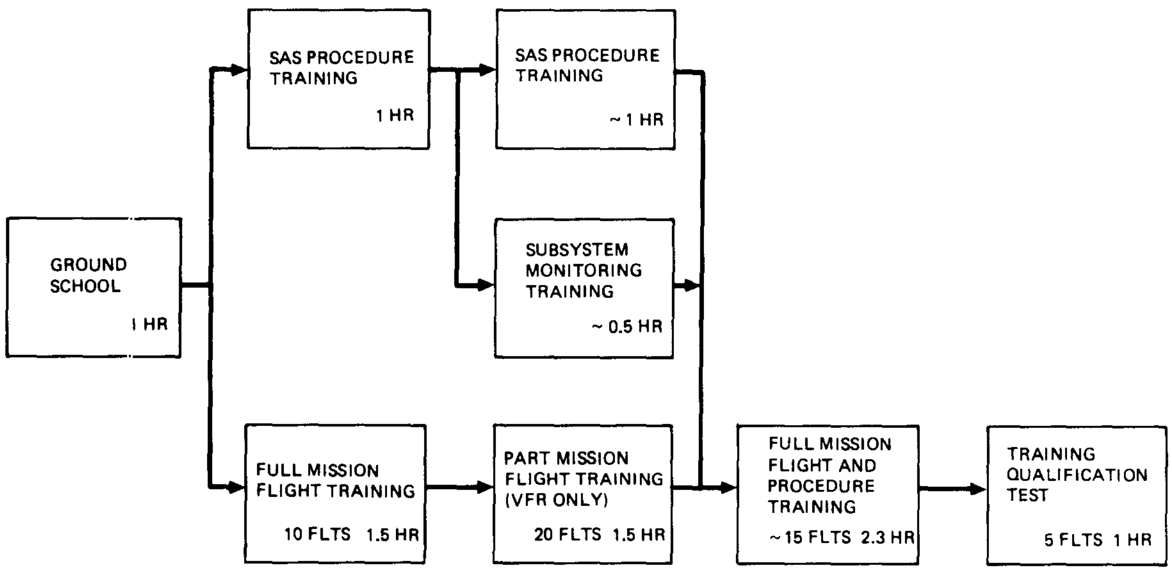


Figure 7: Schematic of Pilot Training Schedule for Flight and Procedure Tasks

Pilot training included groundschool on flight and procedure tasks (Figure 8), cockpit familiarization, procedure task training, visual flight and landing practice, full flight of instrument approaches to visual landings, and full mission flights including emergency procedure tasks. The training was continued until the means and standard deviations of selected performance parameters reached an asymptotic level of acceptable flight performance.

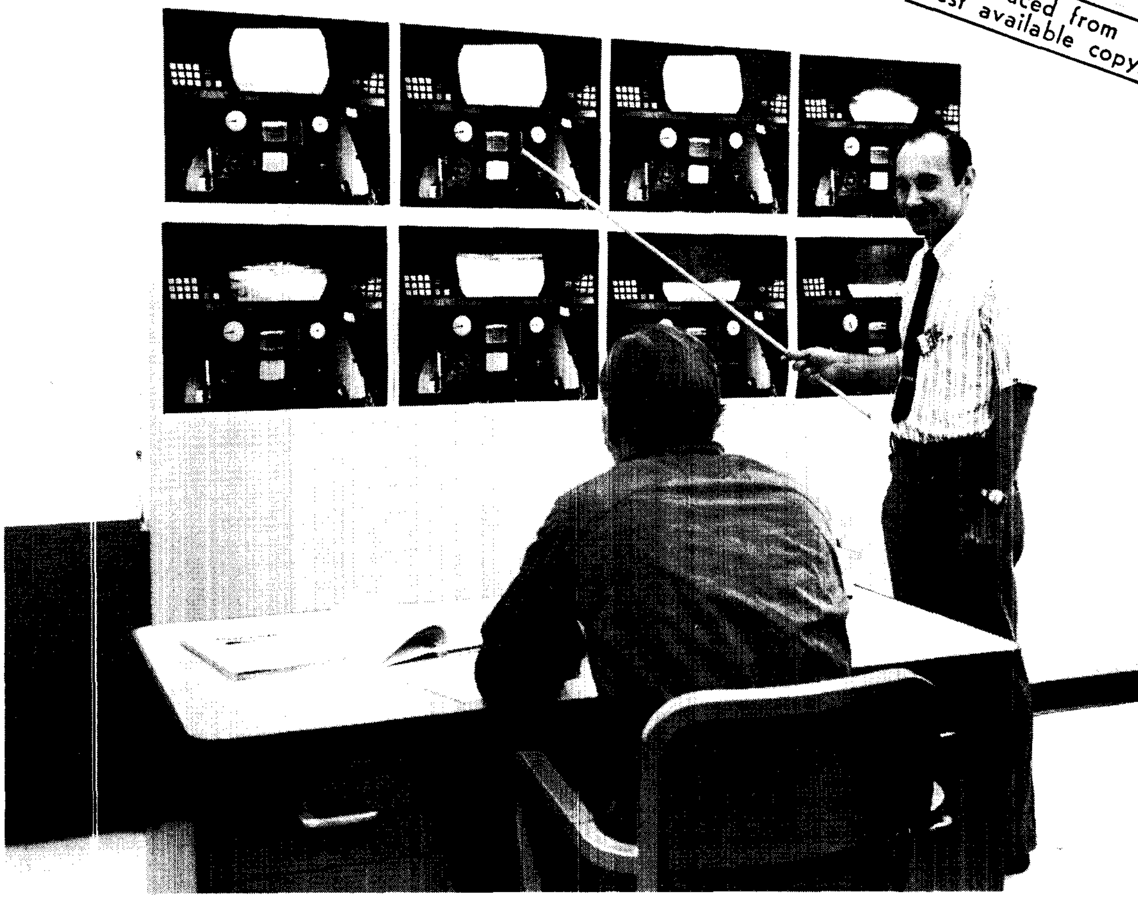


Figure 8: Groundschool Briefing on Flight and Procedure Tasks

The pilots were briefed that their individual scores would be based on their cumulative performance on the following:

(a) Correct procedure taken to rectify emergency situations; the time taken to complete the emergency sequence.

(b) Correct normal operating procedure.

(c) Integrated errors determined from a nominal flight path between control check points or reference planes; and the instantaneous errors observed when crossing those control check points.

The most important of these performance parameters included measurement of lateral and vertical offset from the glide path, airspeed error, and rate of descent. Integrated and instantaneous measurements were taken when the vehicle crossed the vertical planes through the TACAN, at the nominal flare and threshold points, and at touchdown.

The desired goal at touchdown was for a sink rate of from 4 to 6 feet per second, 2000 feet down the runway, on centerline, gear down, and yaw and bank angles near zero. Unsatisfactory performance at touchdown was defined by either of the following: sink rates greater than 12 feet per second, touchdown short or wide of the runway, landing gear up, and/or yaw or bank angles greater than 10 degrees.

Although there were marked, noticeable skill differences between individual pilots, most subjects progressed through training uneventfully. Only one of the original training group of 18 pilots was terminated prior to qualification because of slow progress through the training program; two others were dropped because of incompatible work duties during the retention interval.

All pilots were trained and qualified on both flight control and emergency procedure tasks. The flight control tasks required an average of 48 flights per pilot to train to proficiency, with a range of 30 to 76 flights. In terms of simulator training time, the pilots required an average of 6 hours at the controls to reach qualification. An average of 167 procedure task trials were required for each subject to reach qualification (range 100 to 250). The time expended for groundschool briefing and procedure task training averaged 2.8 hours per pilot. The average training time per pilot amounted to 8.8 hours over 5.3 sessions.

Retention Interval: Method Assignment and Test Preparation

Upon completion of training and collection of the training qualification performance test data, all training materials were recovered from the pilots. The pilots were informed that they were entering the 4 month retention interval phase. During the retention interval, they were not to return to the simulator laboratory, discuss the simulated flight, or perform any piloting functions in other flight simulators or actual aircraft. The pilots were told they would be contacted regarding their retention test schedule two weeks before the end of the retention interval.

The study was designed to compare no practice retention with retention after various refresher techniques by testing three groups of approximately the same overall flight skill capabilities. During the course of the initial training and preliminary test set-up, it was apparent that the available subject population would contain noticeable individual differences in basic flight skills. Also, because of budgetary and time restrictions the groups were limited to a small number of pilots per group (n = 5).

Therefore, it was necessary to establish relative equality between the groups by judicious assignment of the subjects to groups by skill level. The technique used was similar to that used in a randomized blocks or matched groups design. The groups were matched with the expectation that the groups of subjects taken as a unit would be more homogeneous in their response to similar treatments than groups formed by selecting subjects completely at random.

Based upon the scattergram plots of the flight control performance data obtained during qualification, the test subjects were ordered from most proficient to least proficient. The subjects were then assigned to treatment groups. In order to assess group equality, an analysis of variance was completed on each of 32 flight control performance measures using a subjects nested within groups design. A total of four of the ANOVAs showed significant between group differences. Within cell deviation scores were analyzed to determine which of the subjects accounted for these groups differences. Reassignment of 6 subjects was made between the groups and the data was prepared for a new series of ANOVAs.

The second series of 32 ANOVAs of the flight control performance data resulted in no significant group differences ($p > .10$). As would be expected, significant between-subject differences as defined by the F for subjects within groups were found to occur for most of the performance measures. It was concluded that the revised group assignment of subjects provided the desired comparability of groups in performance across all flight control measures. With the assignment of pilots to groups based upon flight performance equality completed, an analysis of the 11 procedure performance parameters using the same experimental design was conducted. No significant differences between treatment groups were found for any of the procedural performance measures.

The initial analyses of the flight test measures were based on data including the arithmetic sign. That is, the sign of the data indicated errors which were high, low, left, or right, short or long. As such, the data provided an indication of not only the magnitude of the error but also its relative direction. However, the arithmetic mean of such data does not reflect the true magnitude of the average error for the 17 flight performance measures which involved direction of error. Therefore, another series of analyses were performed on the absolute error data (i.e., without regard to sign). Once again, no significant differences between groups ($p > .10$) were found for the 32 flight performance measures.

The probability of significant differences between-groups and subjects nested within groups are depicted in Table 1 for each of the 43 performance measures obtained during the pilot training phase. In addition, the average performance for all subjects for each measure is listed. The mean performance values indicated that the subjects had achieved a high degree of performance proficiency at the end of training.

The results of these analyses indicated that no significant group performance bias would affect the evaluation of retraining methods. With this assurance, the three groups were then randomly assigned to

Table 1: Pilot Performance and Analysis of Variance Results (F Ratio) at Completion of Training

		PERFORMANCE MEASURE		GRAND MEAN (ABSOLUTE)	ANOVA SOURCE GROUP	Ss WITHIN GROUPS
TACAN	1	ALTITUDE ERROR	(FT)	357	0.493	3.682***
	2	LATERAL ERROR	(FT)	665	0.453	3.777***
	3	HEADING ERROR	(DEG)	1.5	0.812	2.720***
	4	VELOCITY	(KTS)	245	1.140	1.238
	5	DESCENT RATE ERROR	(FT/SEC)	12.0	0.616	2.445**
	6	INTEGRATED VELOCITY ERROR	(KT-SEC)	971	1.013	10.574***
FLARE	7	ALTITUDE ERROR	(FT)	223	0.509	1.439
	8	LATERAL ERROR	(FT)	100	0.941	3.357***
	9	HEADING ERROR	(DEG)	1.2	0.503	0.462
	10	VELOCITY	(KTS)	230	0.104	2.886***
	11	DESCENT RATE ERROR	(FT/SEC)	13.7	0.396	3.426***
	12	INTEGRATED VELOCITY ERROR	(KT-SEC)	805	2.022	1.875*
	13	INTEGRATED ALTITUDE ERROR	(FT/SEC)	38,944	0.260	1.106
	14	INTEGRATED LATERAL ERROR	(FT/SEC)	70,367	0.133	0.829
THRESHOLD	15	ALTITUDE ERROR	(FT)	45	0.347	3.947***
	16	LATERAL ERROR	(FT)	26	0.448	3.230***
	17	HEADING ERROR	(DEG)	0.7	0.276	2.062**
	18	VELOCITY	(KTS)	189	1.250	3.089***
	19	DESCENT RATE ERROR	(FT/SEC)	8.8	0.025	2.060**
	20	INTEGRATED VELOCITY ERROR	(KT-SEC)	607	0.745	3.540***
	21	INTEGRATED ALTITUDE ERROR	(FT/SEC)	3232	0.266	2.558***
	22	INTEGRATED LATERAL ERROR	(FT/SEC)	1297	0.197	3.683***
TOUCHDOWN	23	LATERAL ERROR	(FT)	21	0.145	2.280**
	24	DOWN RANGE ERROR	(FT)	945	0.699	2.274**
	25	HEADING ERROR	(DEG)	0.5	0.328	1.325
	26	VELOCITY	(KTS)	162	2.440	4.180***
	27	DESCENT RATE ERROR	(FT/SEC)	7.2	0.339	1.254
	28	BANK ANGLE	(DEG)	0.8	1.104	2.115**
	29	PITCH ANGLE	(DEG)	10.8	1.339	6.747***
	30	INTEGRATED VELOCITY ERROR	(KT-SEC)	560	0.609	5.165***
	31	INTEGRATED ALTITUDE ERROR	(FT/SEC)	235	0.630	4.507***
	32	INTEGRATED LATERAL ERROR	(FT/SEC)	195	0.535	2.889
PROCEDURE TASKS	33	INITIAL RESPONSE TIME	(SEC)	2.0	0.118	5.799***
	34	DECISION TIME	(SEC)	1.2	1.618	38.277***
	35	SEQUENCE TIME	(SEC)	0.6	0.021	23.130***
	36	TOTAL TIME	(SEC)	6.0	1.420	3.484***
	37	DECISION ERRORS		0.4	0.615	0.591
	38	SEQUENCE ERRORS		0.1	0.333	0.692
	39	TOTAL ERRORS		0.5	0.409	0.612
	40	NUMBER PROCEDURES WITH ERROR		0.3	0.692	0.703
	41	NO LANDING GEAR		0	0.000	0.000
	42	AUX PWR RESPONSE TIME	(SEC)	2.8	0.760	1.506
	43	NAV FAIL RESPONSE TIME	(SEC)	2.8	0.590	3.664***

* $p < 0.10$
** $p < 0.05$
*** $p < 0.01$

skill retention retraining groups with 5 subjects per group. These groups were: (a) no practice - checklists only; (b) static practice - training manual, photos, and checklists; (c) dynamic display - training manual, photos, checklists and recorded flights. Based upon retraining method assignments to the groups, a schedule was prepared which identified the type of retraining each subject would receive, and the date he was due for skill retention testing.

A critical aspect of experimental programs which suspend complex simulator operations for periods of several months is the ability to maintain a constant experimental test environment. Most critical to an experiment of this type is the ability to maintain the exact display/control relationships, flight dynamics, and visual presentations at the end of the retention interval as was experienced by the pilots at the end of training. In anticipation of this problem, high fidelity calibration recordings of all flight control elements of the simulator were made during the subject training period. These calibration recordings then provided the basis for recalibration prior to subject testing.

One week prior to the date the first subject was to be retested, a complete checkout and recalibration of all simulation equipment was accomplished. The dynamics of the two-axis handcontroller, rudder pedals and speedbrake controls were checked as well as the analog calibration of the electro-mechanical flight instruments. Scaling and sensitivity of the electronic flight instruments (EADI and MFD) were held constant by the digital computer program and hardwired circuit cards.

As an additional measure, the cockpit flight control output voltages were recorded during the training phase and then reflown through the computer prior to testing to determine the empirical equivalence of the flight profile, display control operations, and the visual scene camera servo system. Subjective testing flights were flown by the experimenter pilots to provide a subjective evaluation of the similarity of the aircraft's handling qualities and visual presentation. Comparisons of the flight performance data recorded during training and the data obtained prior to retention testing as well as the subjective evaluation indicated that the simulator was recalibrated to the condition that existed during the training and qualification testing.

Refresher Practice and Retention Testing

Prior to the return of the test subjects, all experimentors and laboratory personnel practiced all test operations to ensure that the experimental procedures were consistent with those previously used during training and were performed without error. To ensure consistency of testing across subjects within each skill retention group, a set of retention test procedures for the experimenter's procedures and written introductory instructions for each retention group were prepared.

At the end of the 4 month retention interval, a different type of refresher training was provided to each of the three groups (Table 2). After each subject arrived in the simulation area, he received the written instructions which indicated to which skill retention training group he had been assigned, a brief description of the refresher training he would receive, the number of flights that he would make, and the amount of time required for testing.

Method Group I. The No-Practice, Checklist-Only Group was tested at the end of the 4 month retention interval with only minimal reintroduction to the pilot task. Upon arrival in the simulator area, the pilot received and read the written introductory instructions and then was seated in the flight simulator cockpit. The seat and rudder pedals were adjusted and the pilot was allowed a few minutes to familiarize himself with the cockpit, the instruments, and control locations. During this time the pilot was allowed to review the flight and procedural checklist.

Table 2: Method Group Refresher Training on First and Sixth Retention Test Flights

	GROUP I: NO PRACTICE	GROUP II: STATIC PRACTICE	GROUP III: DYNAMIC DISPLAY
FIRST RETENTION FLIGHT	• CHECK LISTS (DURING FLIGHT ONLY)	• CHECK LISTS • FLIGHT MANUAL • LARGE PHOTOS	• CHECK LISTS • FLIGHT MANUAL • LARGE PHOTOS • VIEW "CANNED" FLIGHT
SIXTH RETENTION FLIGHT	• WARMUP PRACTICE • CHECK LISTS	• WARMUP PRACTICE • CHECK LISTS • FLIGHT MANUAL • LARGE PHOTOS	• WARMUP PRACTICE • CHECK LISTS • FLIGHT MANUAL • LARGE PHOTOS • VIEW "CANNED" FLIGHT

Review of this checklist provided the pilots with the operational flight plan, key altitude, velocity, and attitude information at specified control points (i.e. at the TACAN station, at flare, etc.) as well as procedural task operations. This checklist did not provide any indication of vehicle idiosyncrasies, descriptions of flight instrumentation, or detailed operational procedures. At the end of the review, the pilot was given a last minute briefing on how to start and reset the simulator.

The first flight was then started. The data from this flight provided the measures of retention performance without the benefits of practice (Table 2, Group I, First Retention Flight). After completion of the retention test flight, the pilot flew an additional four flights. Data was collected on all flights and at the end of each flight the only feedback information that the pilot received was the distance down the runway and descent rate at touchdown.

During the additional four test flights, the pilot could become familiar with vehicle operation, instrumentation and visual cues received during approach and landing. These four flights in combination with the retention interval test flight provided a total of five dynamic warmup practice flights. Upon completion of this series of five flights, the pilot was allowed a 10 minute break during which time he was permitted to get out of the simulator and stretch his legs.

At the end of the rest period, each pilot in Group I was once again tested on his ability to successfully fly the simulated approach and landing mission. The data from this sixth retention test flight was used to assess the effects of dynamic warmup practice on skill retention (Table 2, Group I, Sixth Retention Flight).

Method Group II. The Static Rehearsal Group received detailed briefings from the flight handbooks which covered flight vehicle characteristics, the displays and controls, flight operations, flight procedures, and emergency procedure operations at the end of the retention interval. Upon arrival in the simulation area, the pilot was provided with the written instructions which indicated to which group he had been assigned, the type of retraining practice he would receive and the number of flights he would fly. The pilot was then taken to the briefing room and provided with the flight control and procedural checklists, the training manual which was used during initial training, and a series of 60 percent life-size photographs of the cockpit at key flight control points in the mission profile.

These photographs depicted instrument information and the external visual scene as seen through the cockpit windscreen at each key control point. This static representation of the task environment at the critical control points, permitted the pilots to follow the essential elements of the flight through the descent, approach and landing. Through the use of these large scale photographs, the flight control information provided by the instruments was correlated with the visual scene. The pilot thereby gained an appreciation for vehicle altitude and attitude during the critical visual portion of the flight (Figure 9). Each photograph was labeled with a brief description of the critical mission control point, and accompanied with the flight plan checklist, the pilot could project himself into the task environment.

Figure 9: Static Rehearsal Group (II) Pilot Reviewing Large Scale, Critical Control Point Photographs

The pilot was permitted 40 minutes to review this material and prepare himself for flight testing. At the end of the 40 minutes, he returned to the simulation area and was seated in the simulator cockpit. The seat and rudder pedals were adjusted and a few minutes were allowed for re-familiarization of the cockpit using the checklists and the training manual. At the end of the familiarization period, the subjects were given a last-minute briefing on the operation of the simulator controls to start and stop the flights. The remaining sequence of events were identical to those for subjects in Group I.

The performance on the first retention test after the retention interval was compared to the qualification performance obtained at the end of training to the effects of static rehearsal training on skill retention performance. As with Group I, Group II also received an additional four test flights to complete the dynamic warmup practice (Table 2). The sixth retention test provided the basis for analyzing the benefits of combined static and dynamic refresher training.

Method Group III. The Dynamic Display Group received the same refresher training provided to the Static Rehearsal Group. However, upon the completion of the briefing session and cockpit familiarization, the pilots were permitted to view three fully dynamic flights from the cockpit. These fully dynamic flights were produced from recorded control signals from selected, previously flown flights. The recordings were played back through the computer simulation equipment to operate the cockpit displays and provide the out-the-window visual scene. During each of these flights, the pilot was instructed to pay particular attention to the dynamics of the information presented by the cockpit instruments in relation to the visual scene depicted during the approach and landing phase of the mission. He was to observe the detailed dynamic progression of each flight, including minor pilot errors and corrective actions that could be used to successfully land the vehicle. Operating as an open-loop simulator, the Dynamic Display method provided an exact representation of the task environment throughout the entire mission.

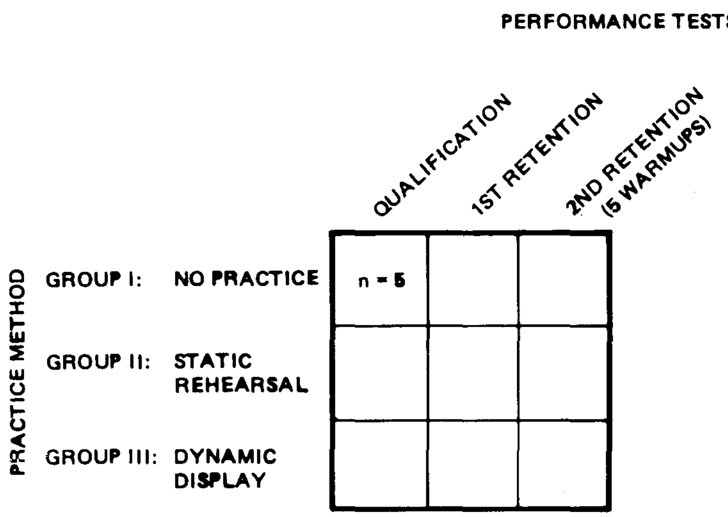
Dynamic display practice for the procedure task was similar to the flight control task with the exception that the pilots did not view an automated "canned" representation of the task operations. Instead, they watched an experimenter run through several operations of each procedure sequence. This approach provided procedure task rehearsal with dynamic sequencing of display information and control input responses which was comparable to the dynamic display method for flight control.

Once again, performance for this method group was measured during the first test flight. This data, compared to the performance obtained at the end of training, provided for the evaluation of dynamic display practice. Additional test flights were then flown to provide dynamic warmup for the evaluation of the combination of dynamic display and dynamic warmup practice (Table 2).

3. RESULTS

Eleven performance measures were used to evaluate flight control performance. Six of the performance measures were repeated at four points in the flight, two measures were taken during three flight phases, and two additional measures were taken during the final phase. This provided a total of 32 flight control data measurements. A total of eleven measures were used to evaluate performance for the procedure tasks. Performance was measured at the end of training (qualification test), at the end of the retention interval (retention test), and after five test flights (warmup test).

Each of these performance measures were subjected to the analysis of variance statistic to evaluate the effects of no practice and refresher training on skill degradation. The two factor (retraining methods by performance tests) experimental design with repeated measures on the test factor (subjects nested within groups) is depicted in Figure 10. It may be seen that the effects of methods are confounded with subject groups while the effects of tests and the test by method interactions are free of such confounding. However, there were only slight differences across method groups as the subjects were assigned to matched groups based upon qualification performance.



ANOVA SUMMARY

SOURCE	DF
BETWEEN SUBJECTS	14
METHODS (M)	2
Ss WITHIN GROUPS	12
WITHIN SUBJECTS	30
TESTS (T)	2
T x M	4
T x Ss WITHIN GPS	24
TOTAL	44

Figure 10: Experimental Design for Effects of No Practice and Retraining Practice Methods on Skill Retention

Flight Control Task

A total of 32 measures of flight control performance were obtained and analyzed during the descent, approach and landing of the vehicle. Based upon three of these measures, one critical measure of operational significance was derived: landing success; that is, did the vehicle land (a) on the runway, and (b) with a descent rate within the tolerance of the landing gear structural strength. In addition, 26 of the 32 individual performance variables were integrated in a combined flight performance measure to assist in the overall interpretation of the results.

Crash Landing Criteria

The occurrence of a crash landing was used as one criterion of performance by which the retention interval practice methods were compared. A landing that was short of the runway or a touchdown so far down the runway (> 5,000 ft) as to cause the vehicle to run off the end, a landing that was off the runway to the right or to left, or a landing that was so hard as to collapse the landing gear (16 ft/sec) was a crash landing which could destroy the vehicle. Lateral error, down range error and descent rate at touchdown were evaluated as crash criterion measures for the three method groups. Summarization of this data is depicted in Table 3. The frequency of occurrence of short (long), hard, and wide landings is presented as a function of each retention interval practice condition.

It can be readily seen that the absence of any type of retention interval practice was disastrous. Each of the five pilots in Method Group I crash landed the vehicle at the end of the four month retention interval as defined by one or more of the crash condition criteria. Dynamic warmup practice afforded by the five practice flights reduced the number of crash landings to two. Static rehearsal practice (Group II) prior to testing at the end of the retention interval reduced the occurrence of crash landings experienced by the no practice group by three. This static rehearsal resulted in only two crash landings, which was the number experienced by the pilots with dynamic warmup practice only. The addition of warmup practice to static rehearsal practice eliminated the incidence of crash landings completely. Only the dynamic rehearsal for Group III resulted in no crash landings at the end of the retention interval.

Table 3: Frequency of Crash Landings on Retention Test Flights as Function of Practice Method

CRASH CONDITION	GROUP I		GROUP II		GROUP III	
	NO PRACTICE	DYNAMIC WARMUP	STATIC REHEARSAL	S-R AND WARMUP	DYNAMIC DISPLAY	D-D AND WARMUP
SHORT (LONG)	2	1	1			
HARD	5		2			1*
WIDE	2	2	1			1*
TOTAL PILOTS WITH CRASH	5	2	2			1*

*EXPERIMENTAL ARTIFACT, SEE TEXT

The combination of dynamic rehearsal and warmup did produce one crash landing. In this case the pilot landed off the runway with a descent rate that exceeded the capacity of the landing gear. However, during the final landing phase of this flight, the visual scene produced by the simulator was disrupted a short period of time (approximately 5 to 10 secs). Evaluation of the pilot's data and experimental test records showed that he was lined up with the runway at approximately the correct altitude when crossing the runway threshold. After the disruption, he ballooned the landing and deviated off course, followed by a stall and crash off the side of the runway. In this case, there is good reason to believe that in the absence of any simulator malfunction the pilot would have landed successfully. Inspection of the immediately preceding and following flights confirmed his ability to land successfully. It was concluded that this crash was an experimental artifact and not considered further.

The frequency of crash landings which occurred for each of the retention interval practice methods was compared using the Chi square technique. A significant value of X^2 ($p < .01$; $X^2 = 15.75$ with 5 df.) was obtained, which indicated that the proportion of crash landings differed across the retention interval no-practice/practice method groups. The difference is a function of the high number of crash landings (5 out of 5) which occurred for the no practice group.

Combined Flight Performance Measure (CFPM)

The CFPM is an expression of overall piloting performance throughout the entire flight in one measure. The measure was determined by equally weighting all of the error performance measures (except heading) at each of the four critical flight control points (TACAN, Flare, Threshold, Touchdown). Heading "errors" (deviations from an ideal course line) were not considered because these were generally less than 2 degrees and were usually indicative of a corrective action taken to decrease the apparent lateral error at the moment. Likewise, pitch and bank angle error at touchdown were not included in the combined measure as the deviations were very small and usually corrective in nature. Thus, of the 32 flight performance measures, 26 were used to derive the CFPM.

A baseline performance level was determined for each measure by its average value in all qualification performance tests. This nominal or "qual" level was used to establish the performance factor or ratio for each data measurement that was taken. That is, the flight performance factor for a data measurement was the actual value measured, divided by the mean of that parameter in all qualification tests. Since the CFPM was evolved to give a picture of the flight overall,

all the parameters were given equal weight. The 26 flight performance factors were, therefore, arithmetically averaged to provide the overall combined flight performance measure for each flight.

Overall flight control performance was evaluated using the CFPM for the total flight. Figure 11 depicts the effects of no practice and the retraining methods on skill retention for the total flight. The data is plotted relative to the average performance achieved by all subjects in the three method groups as indicated by the qual level reference line.

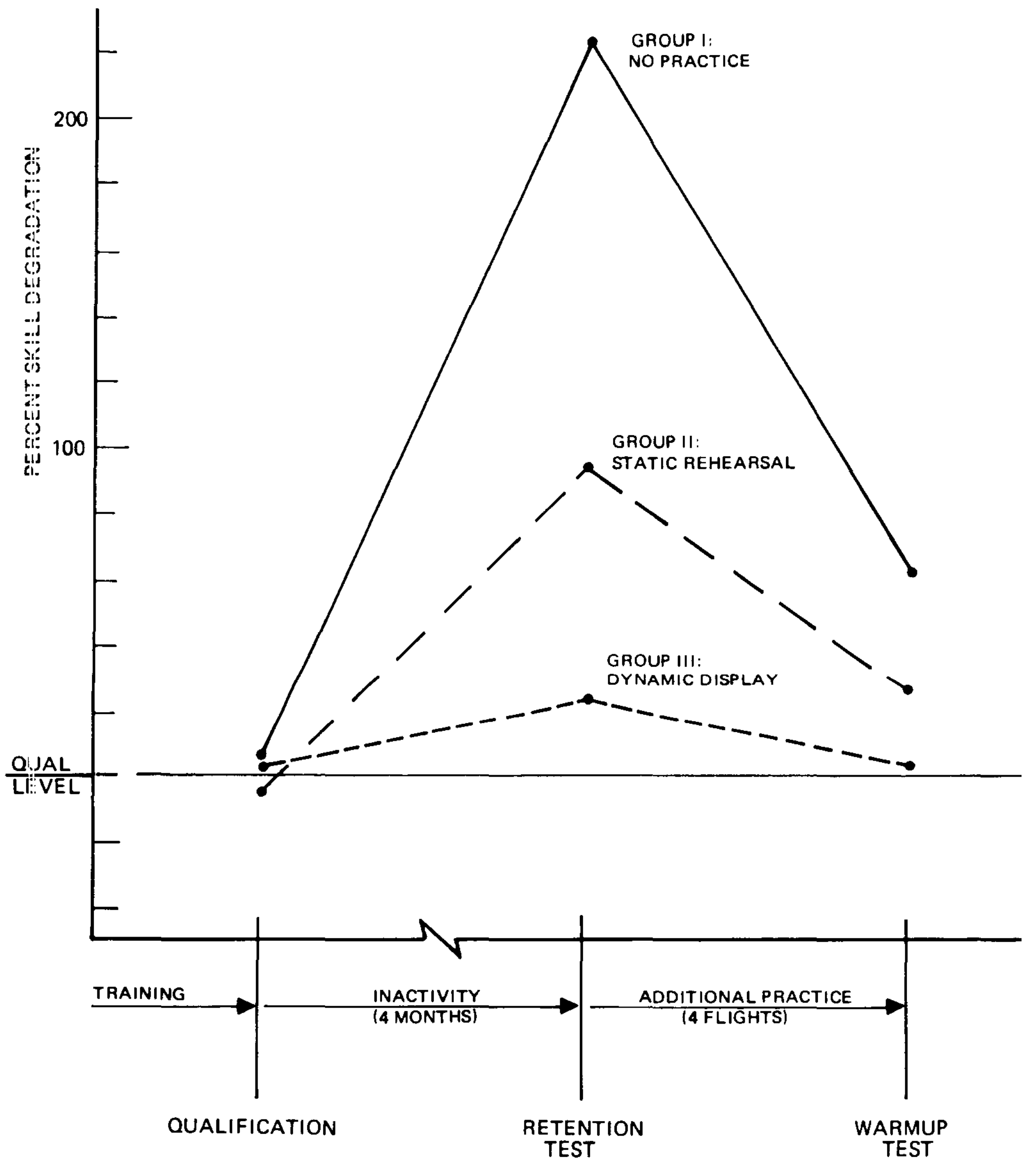


Figure 11: Skill Retention as a Function of Practice Method (Based on Combined Flight Performance Measure)

A tests by methods ANOVA, with subjects nested within methods, was used to analyze differences between groups and performance tests on the combined flight performance measure. The retention test data evaluated the effects of no practice, static rehearsal and dynamic display rehearsal for Method Group I, II, and III, respectively. The warmup test data evaluated the effects of dynamic warmup practice, static rehearsal with dynamic warmup, and dynamic display rehearsal with dynamic warmup for the three groups.

The results of this analysis are depicted in the overall flight part of Table 4, with significant differences ($p < .01$) detected for both main effects and for the interaction. The significant methods effect indicated that retention performance improved as a function of practice method. The addition of warmup practice further improved retention performance for the three groups as shown by the significant tests effects. However, the methods by tests interaction showed that the benefit of warmup practice was most strongly associated with the groups that had less efficient or no retention training. The impact of warmup on Group III (dynamic display) performance was minimal since retention performance after 4 months was so high to begin with.

The data were further analyzed using the Duncan's New Multiple Range Test. Performance of both the no practice group and the static rehearsal group was significantly degraded at the end of the retention interval (Duncan's, $p < .05$), while the dynamic display rehearsal group showed no significant and very little practical degradation. However, the static rehearsal group performance was significantly better than the no practice group (Duncan's, $p < .05$). Warmup practice significantly (Duncan's, $p < .05$) reduced the no practice degradation (Group I); however, performance still showed a very strong trend toward degradation when compared to qualification performance. The addition of dynamic warmup practice to static rehearsal likewise significantly reduced the amount of degradation for Group II (Duncan's, $p < .05$). In this case, however, the combination of the two methods reduced degradation considerably more than either method used singly.

and while some degradation still existed, it was probably not of practical significance. No significant differences were found between qualification performance and retention tests for Group III.

Table 4: Analysis of Variance Results (F Ratio) for the Combined Flight Performance Measure

MISSION PHASE	SOURCE		
	TESTS	METHODS	T x M
OVERALL FLIGHT	22.24***	4.58**	5.59***
TACAN	8.67***	1.45	1.47
FLARE	4.61**	20.00***	9.11***
THRESHOLD	4.14**	1.86	1.13
TOUCHDOWN	1.60	4.38**	1.23

* $P < .10$
** $P < .05$
*** $P < .01$

Similar results were obtained when performance during each flight phase was evaluated. The four flight phases were: 1) Start to TACAN (IFR); 2) TACAN to flare (VFR); 3) flare to threshold (VFR); and 4) threshold to touchdown (VFR).

Figure 12 depicts performance as measured by the CFPM as a function of flight phase. The CFPM data for each flight phase were analyzed using the same ANOVA as for the overall flight; these results are also shown in Table 4. It can be seen that the dynamic display method was extremely powerful for the three phases which involved out the window vision (VFR). Only for the data taken at the TACAN (IFR) was the dynamic display method inadequate after 4 months without practice. A slight improvement over static rehearsal was noted, but the magnitude was of no practical or statistical significance.

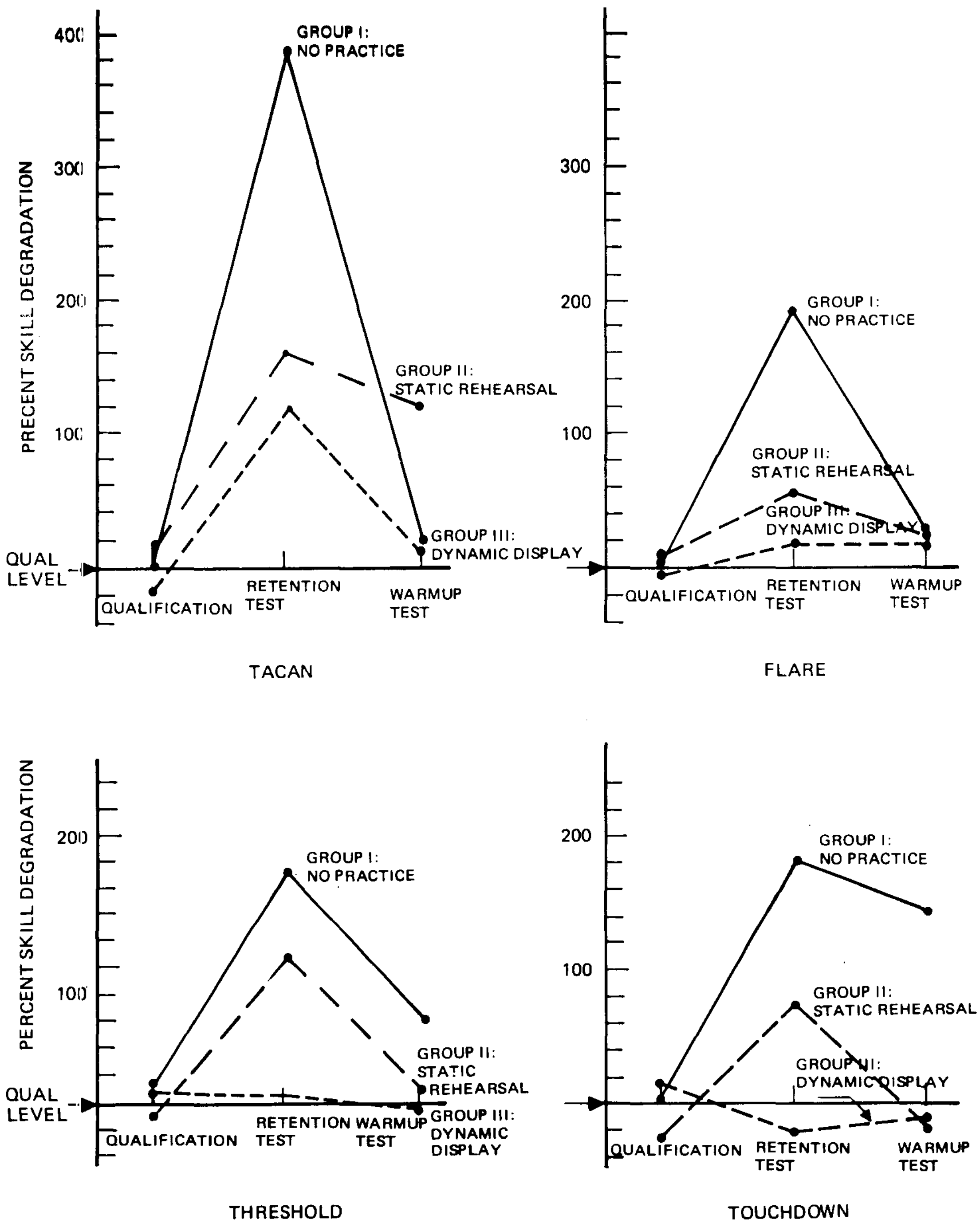


Figure 12: Skill Retention as a Function of Practice Method for Four Critical Flight Phases (Based on Combined Flight Performance Measure)

Another difference noted in the data taken at the TACAN was the failure of static rehearsal plus dynamic warmup (Group II) to reinstate performance while dynamic warmup alone (Group I) did. This apparent inconsistency is easily understood in relation to the total piloting task during this flight phase. In addition to flying, the pilots were required to perform a number of emergency flight procedure tasks. The static rehearsal group (II) attempted to perform on both the flight control and procedure tasks. Without the benefit of rehearsal, the pilots in the no practice group (I) had considerable trouble with the procedure task; as a result, most just ignored the procedure completely. Group I, therefore, spent all their time concentrating on flying while Group II worked on both tasks. This part task versus whole task difference accounted for Group I's dramatic improvement with warmup practice. As can be seen, the combined flight control performance measure showed the same overall results in terms of method selection as did the frequency of crash landings.

Individual Flight Control Performance Measures

In order to provide additional insight into the degradation process and effects of retraining methods, the results obtained from each of the 32 separate flight control performance measures are depicted in Table 5. Based upon normal operational limits, the majority of the performance measures showed degradation of practical importance. However, some measures can be considered to have little practical or operational significance for this task. For example, heading error at the threshold increased by a factor of 9 with no practice (Method 1, qual to no practice). However, the maximum error without practice was only 1.8 degrees, still considerably better than the normal performance limit of $\pm$ 5.0 degrees for a VFR approach.

It should be noted that for Table 5 an increase in numerical size indicates increased degradation for error measures of performance only. Deviation up or down from the qualification performance levels are indications of degradation for the velocity, bank angle and pitch angle measures.

Table 5: Mean Performance as a Function of Practice Methods for Individual Flight Control Performance Measures

		PERFORMANCE MEASURE	GROUP I: NO PRACTICE			GROUP II: STATIC REHEARSAL			GROUP III: DYNAMIC DISPLAY		
			QUAL	RET TEST	WARMUP	QUAL	RET TEST	WARMUP	QUAL	RET TEST	WARMUP
TACAN	1	ALTITUDE ERROR	520	1891	873	390	1884	1321	102	736	118
	2	LATERAL ERROR	137	1637	360	847	884	1101	200	1968	397
	3	HEADING ERROR	1.1	1.4	1.0	1.4	3.7	2.2	1.5	4.4	2.2
	4	VELOCITY	243	281	239	242	243	241	246	241	248
	5	DESCENT RATE ERROR	18	41	9	9	27	13	6	13	16
	6	INTEGRATED VELOCITY ERROR	720	2709	852	828	1176	1099	1198	1369	1180
FLARE	7	ALTITUDE ERROR	261	458	500	278	397	156	322	183	183
	8	LATERAL ERROR	105	137	105	73	127	70	80	32	109
	9	HEADING ERROR	.7	1.9	1.2	1.3	.7	1.2	1.4	1.6	1.0
	10	VELOCITY	231	214	238	227	232	230	234	230	233
	11	DESCENT RATE ERROR	10	36	7	16	19	20	8	21	15
	12	INTEGRATED VELOCITY ERROR	637	3505	800	996	1553	1399	898	1556	1242
	13	INTEGRATED ALTITUDE ERROR	56.8K	89.3K	77.2K	40.5K	106.3K	59.4K	50.2K	59.4K	51.5K
	14	INTEGRATED LATERAL ERROR	110.0K	172.0K	146.8K	137.9K	197,4K	152.8K	110.9K	137.4K	131.3K
THRESHOLD	15	ALTITUDE ERROR	68	72	167	38	69	39	82	60	34
	16	LATERAL ERROR	26	90	52	26	27	37	47	13	26
	17	HEADING ERROR	.3	1.6	1.0	.4	.8	.6	1.2	.6	.7
	18	VELOCITY	191	154	206	191	151	183	198	181	191
	19	DESCENT RATE ERROR	10	33	13	12	12	12	12	4	7
	20	INTEGRATED VELOCITY ERROR	595	1004	342	593	816	716	441	744	577
	21	INTEGRATED ALTITUDE ERROR	4051	4046	7299	4064	5133	2542	4491	2674	2237
	22	INTEGRATED LATERAL ERROR	1189	1899	1801	1147	1705	982	1060	540	1245
TOUCHDOWN	23	LATERAL ERROR	20	83	24	28	43	32	29	14	54
	24	DOWN RANGE ERROR	1322	4360	2416	695	2708	935	1370	1573	1577
	25	HEADING ERROR	.2	1.8	.9	.2	1.5	.4	.7	1.2	.6
	26	VELOCITY	161	179	155	168	181	162	164	163	154
	27	DESCENT RATE ERROR	7	35	12	8	22	7	8	9	7
	28	BANK ANGLE	1.2	3.3	1.6	.4	1.3	2.8	1.3	.5	.7
	29	PITCH ANGLE	11	6	11	11	7	11	10	11	12
	30	INTEGRATED VELOCITY ERROR	627	733	960	431	554	382	647	360	707
	31	INTEGRATED ALTITUDE ERROR	377	346	1593	116	299	106	457	295	305
	32	INTEGRATED LATERAL ERROR	229	451	539	139	308	203	391	147	396

The data were analyzed using the two factor, analysis of variance design with repeated measures on one factor (subjects nested within groups). The results of the 32 analyses are depicted in Table 6. The data for each of the 32 individual measures showed trends comparable to the crash criteria and the combined flight performance measure data. However, due to the small sample size, the analysis failed to detect significant differences for many of the individual measures.

Procedure Task

Eleven measures of time and error performance were used to evaluate performance for the three procedure tasks: Subsystem Scan failure monitoring, Stability Augmentation System (SAS) failure monitoring and control and landing gear actuation. The data for each procedure performance measure were analyzed using the same two factor analysis of variance design with repeated measures on one factor as was used for the flight control analysis. Once again, the factors were retention methods and performance tests.

As overall indicators of performance, the SAS procedure measures of total time and total errors were representative of all the procedure task data. They combine relatively pure psychomotor performance with the more complex decision/response performance. Analogous to the combined flight performance measure, these total performance measures are presented separately to provide an integrated view of the effects of retraining methods on procedure performance.

SAS Total Time and Errors

The results indicated that procedure performance degraded significantly after four months without practice. As overall measures of performance, the average total time required to perform the procedure task is depicted in Figure 13 and the average number of total errors per procedure is depicted in Figure 14 for each of the retention methods.

No significant differences were found between the static rehearsal, dynamic display, and warmup retraining methods for the measure of

Table 6: Analysis of Variance Results (F Ratio) for Individual Flight Control Performance Measures

PERFORMANCE MEASURE			SOURCE		
			TESTS	METHODS	T x M
TACAN	1	ALTITUDE ERROR	5.79***	2.72	0.46
	2	LATERAL ERROR	2.94*	0.09	0.86
	3	HEADING ERROR	2.81*	1.60	0.54
	4	VELOCITY	2.22	2.56	3.01**
	5	DESCENT RATE ERROR	5.40**	1.39	1.72
	6	INTEGRATED VELOCITY ERROR	7.43**	1.51	4.12**
FLARE	7	ALTITUDE ERROR	0.49	2.02	2.09
	8	LATERAL ERROR	0.14	1.32	1.60
	9	HEADING ERROR	0.20	0.22	0.69
	10	VELOCITY	0.59	0.09	0.59
	11	DESCENT RATE ERROR	5.43**	0.41	2.51*
	12	INTEGRATED VELOCITY ERROR	13.03***	0.66	5.34***
	13	INTEGRATED ALTITUDE ERROR	4.35**	1.24	1.02
	14	INTEGRATED LATERAL ERROR	4.51**	2.86*	0.37
THRESHOLD	15	ALTITUDE ERROR	0.34	1.93	2.52*
	16	LATERAL ERROR	0.35	9.70***	3.07**
	17	HEADING ERROR	0.56	0.75	1.49
	18	VELOCITY ERROR	3.50**	0.35	0.47
	19	DESCENT RATE ERROR	1.22	3.02*	2.96**
	20	INTEGRATED VELOCITY ERROR	5.96***	0.23	1.56
	21	INTEGRATED ALTITUDE ERROR	0.04	1.71	2.78*
	22	INTEGRATED LATERAL ERROR	0.59	2.73	2.01
TOUCHDOWN	23	LATERAL ERROR	1.21	0.34	2.46*
	24	DOWN RANGE ERROR	2.38	1.48	0.57
	25	HEADING ERROR	2.33	0.25	1.06
	26	VELOCITY	1.90	0.35	0.24
	27	DESCENT RATE ERROR	6.46***	3.01*	2.33*
	28	BANK ANGLE	0.69	0.60	1.53
	29	PITCH ANGLE	6.77***	1.06	2.29*
	30	INTEGRATED VELOCITY ERROR	0.39	1.22	0.69
	31	INTEGRATED ALTITUDE ERROR	2.01	2.34*	3.24**
	32	INTEGRATED LATERAL ERROR	0.39	0.76	0.65

* $p < 0.10$

** $p < 0.05$

*** $p < 0.01$

total time. The highly significant tests effect ($p < .005$) was due primarily to the large amount of degradation experienced by Group I with no practice at the retention test. This same condition was probably the primary factor in the strong methods effect trend. However, the 100 percent degradation experienced for the static rehearsal method after 4 months without practice must be considered a contributor to the methods effect trend.

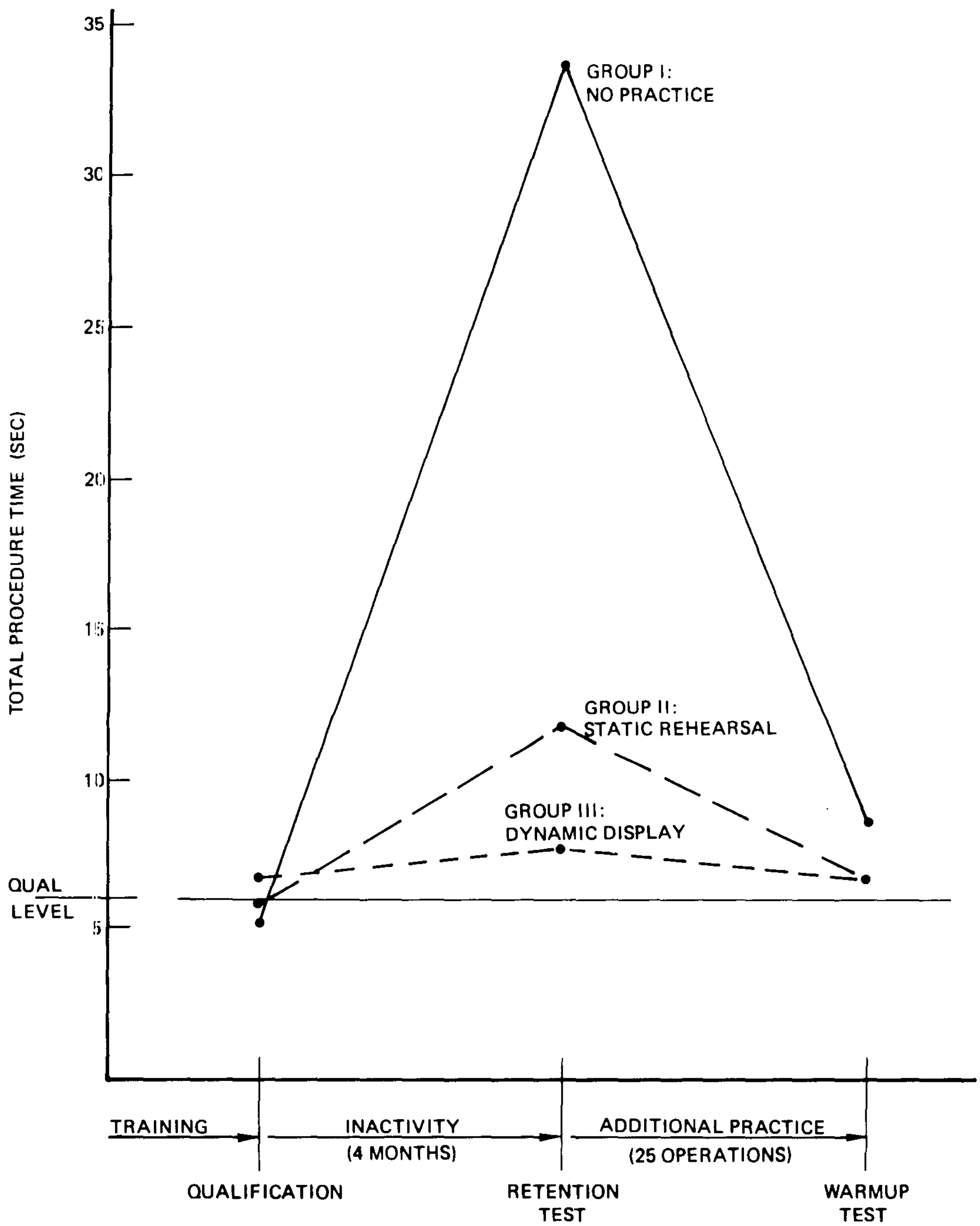


Figure 13: Average Total SAS Procedure Time as a Function of Practice Method

The results were similar for the measure of total errors. The only difference was that static rehearsal without warmup showed no practical or significant trend toward degradation. While the dynamic display group showed a greater total error average, this was a general elevation across tests. Retention performance in relation to performance at the end of training showed that the magnitude of degradation of the dynamic display group was comparable to that of the static rehearsal group.

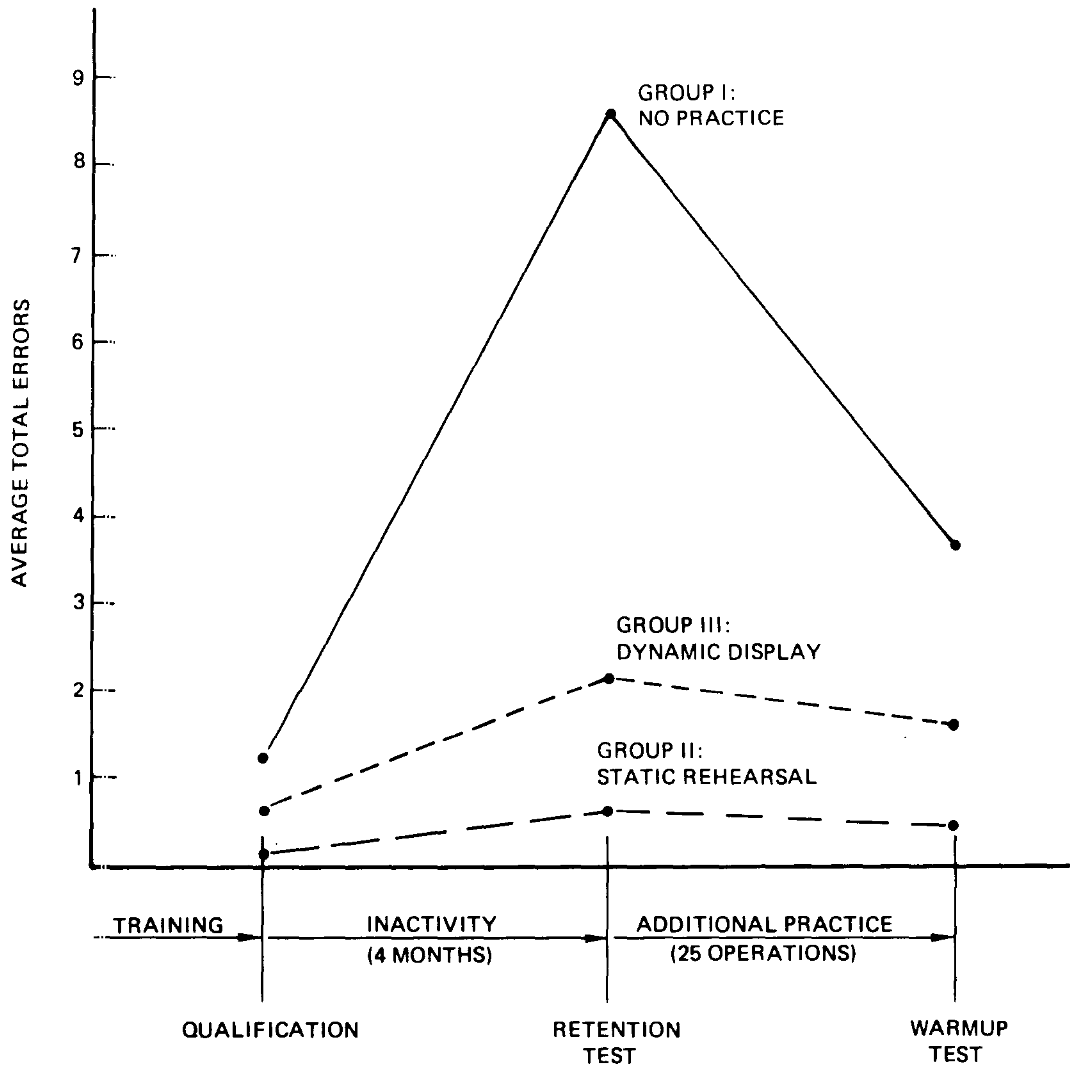


Figure 14: Average Number of Errors Per SAS Procedure Operation as a Function of Practice Method

Individual Procedure Performance Measures

The effects of the practice methods on all of the procedure performance measures are depicted in Table 7. In addition to SAS total time and error, measures of the discrete elements of the SAS failure procedure, the response times associated with the Subsystems Scan (Auxiliary Power and Terminal Navigation failures), and landing gear status at touchdown are included.

Table 7: Mean Performance as a Function of Practice Methods for Procedure Performance Measures

	PERFORMANCE MEASURE	GROUP I: NO PRACTICE			GROUP II: STATIC REHEARSAL			GROUP III: DYNAMIC DISPLAY		
		QUAL	RET TEST	WARMUP	QUAL	RET TEST	WARMUP	QUAL	RET TEST	WARMUP
33	INITIAL RESPONSE TIME	1.76	6.73	2.44	1.99	3.00	2.07	1.84	1.99	1.94
34	DECISION TIME	.99	6.91	1.23	1.21	2.56	1.31	1.14	1.47	1.23
35	SEQUENCE TIME	.56	6.99	.84	.60	1.27	.73	.66	.75	.59
36	TOTAL TIME	5.07	32.97	8.31	5.56	11.45	6.39	6.48	7.52	6.59
37	DECISION ERRORS	.2	5.6	2.2	0	.6	.4	1.0	1.6	.8
38	SEQUENCE ERRORS	.4	3.0	1.4	0	0	0	.2	.6	.8
39	TOTAL ERRORS	.6	8.6	3.6	0	.6	.4	1.2	2.2	1.6
40	NUMBER PROCEDURES WITH ERRORS	.2	3.8	2.2	0	.6	.2	.4	1.0	.6
41	NO LANDING GEAR	0	2	0	0	1	0	0	0	0
42	AUX PWR RESPONSE TIME	2.78	11.30	5.04	2.52	4.18	3.04	2.54	2.86	2.56
43	NAV FAIL RESPONSE TIME	2.88	82.56	29.78	4.14	3.50	3.20	2.70	2.54	2.42

The results of the statistical analyses for each measure of procedural performance are depicted in Table 8. As can be seen, the data and the results of the statistical analyses for these measures were similar to the SAS Failure total time and error measures. Performance without practice degraded significantly and the application of dynamic warmup practice reduced the degradation to performance levels which approached those achieved at the end of training (Group I).

While not statistically significant, there was a definite trend toward degradation for the static rehearsal method (Group II). For all practical purposes, the addition of dynamic warmup practice to static rehearsal reinstated performance to training qualification levels. After 4 months without practice, the dynamic display retraining method (Group III) virtually maintained performance at the qualification levels. The extremely minor performance differences were generally further reduced by the addition of warmup practice; however, the differences were so small that not even a hint of statistical trends were detected.

Table 8: Analysis of Variance Results (F Ratio) for Procedure Performance Measures

PERFORMANCE MEASURE		SOURCE		
		TESTS	METHODS	T x M
33	INITIAL RESPONSE TIME	11.57***	6.60**	6.16***
34	DECISION TIME	15.22***	5.58**	7.19***
35	SEQUENCE TIME	4.84**	3.31*	3.47**
36	TOTAL TIME	8.02***	3.06*	4.08**
37	DECISION ERRORS	10.39***	6.06**	5.46***
38	SEQUENCE ERRORS	2.15	6.18**	1.52
39	TOTAL ERRORS	8.56***	6.45**	4.88***
40	NUMBER PROCEDURES WITH ERRORS	11.37***	6.55**	4.50***
41	NO LANDING GEAR	3.60**	1.20	1.20
42	AUX PWR RESPONSE TIME	14.96***	9.17***	7.88***
43	NAV FAIL RESPONSE TIME	3.90**	4.79**	3.99**

* $P < .10$
** $P < .05$
*** $P < .01$

4. DISCUSSION

During training, many of the pilots made unsolicited comments relative to the simulation and the tasks they were required to perform. The simulation was well accepted by the pilots with a consensus that the simulation was very good and required maximum concentration of pilot abilities throughout each flight phase. The general impression obtained, from observation throughout the course of the study, was that the pilots were faced with a difficult task. Both observation and pilots comments indicated that the emergency procedure task during flight tended to produce a task load situation comparable to that found in actual flight emergencies. The task became particularly stressful when the pilot made errors while performing emergency procedures.

The general conclusion was that the simulation was a realistic reproduction of a representative approach and landing for a large flight vehicle. The test subjects were all experienced pilots. While their experience with the simulated vehicle was less than normally found in operational situations, they were well trained to a consistent and asymptotic level of operationally acceptable performance. The greater number of performance measures, their combination into a total measure (the CFPM), the availability of an operationally practical measure of performance (crash landings), and the use of pilots as subjects resulted in a more stable and consistent assessment of flight control skill degradation than in a previous study of instrument flight control of a booster launch (Sitterley and Berge, 1972).

The results showed that pilot performance after 4 months without practice was significantly degraded for both flight control and procedural tasks. The magnitude of visual flight control degradation was comparable to that found in the previous study of booster flight control. In the present study, the instrument flight control phase also resulted in almost twice the amount of degradation experienced during the visual portion of the flight.

It has been postulated that visual flight control (VFR) would be subject to greater skill degradation than instrument flight control (IFR) because of the greater complexity of the perceptual/motor coordination and integration process. The finding that this was apparently not the case (Figure 12) may be the result of relatively higher task loading of the IFR portion of the flight. In this study, the pilots were required to both fly and respond to procedure emergencies. Even though the emergency procedures were seldom successful without adequate practice, their occurrence, and the pilots' inability to handle them, had a disturbing and disrupting influence on flight control performance.

The procedure task results showed greater magnitudes of degradation than that found for flight control. However, the magnitude of degradation on the SAS procedure was less than found by Sitterley and Berge (1972). While the same basic procedure logic was used for both the SAS procedure and the procedure previously reported, the test subjects in this study were considerably more experienced in handling task loaded, multiple operations.

While reviews of many previous studies have indicated that dynamic warmup practice is required to maintain continuous flight control skills (Naylor and Briggs, 1961; Gardlin and Sitterley, 1972), this study failed to find a difference in performance between carefully structured static rehearsal and dynamic practice. Further, neither the static rehearsal nor the dynamic warmup practice in the amounts provided were sufficient to reinstate performance to the levels achieved at the end of training.

It is postulated that the dynamic warmup practice reinforced the psychomotor and perceptual elements of the task. However, without the thorough review of the operational flight plan and recommended flight procedures afforded by the static rehearsal, the amount of dynamic practice would have to be substantially increased to reinstate the coordination and timing of maneuvers and operational subtleties of the task. On the other hand, static rehearsal reinforced the understanding of operational procedures, appropriate control/ decision responses, and recommended maneuver sequences. Further, it is probable that to some extent, the perceptual flight cues were partially reinforced through the use of the series of photographs. However, the static rehearsal method did not adequately handle the perceptual/ vehicle response coordination cues.

This interpretation of the effects of the dynamic warmup and the static rehearsal methods was supported by the data obtained from Group II. When the two techniques were combined, no crash landings were observed and degradation as measured by the CFPM was virtually eliminated. Apparently the two methods were highly complementary, each providing the skill reinforcement the other lacked.

In some situations, static rehearsal alone might be considered for retraining. The results of this study showed that several aspects of flight control and procedural performance may be maintained using static rehearsal. On the other hand, while experimentally important in the evaluation of retraining methods, dynamic practice would not be used by itself in a real world training situation. There is no reason of practicality or feasibility not to include static rehearsal if a dynamic practice retraining is used. The combination of both methods, with the amount of dynamic practice increased over the levels used in this study, can be expected to reinstate all aspects of flight and procedural performance.

One of the most interesting results was that no practical or significant degradation was found for the dynamic display rehearsal group. They received the same refresher training as did the static rehearsal group with one important difference. That difference was the inclusion of a more complete representation of the visual flight environment which provided the appropriate dynamic perceptual cues (e.g. depth, closure rate, and parallax). The pilots did not, however, have the benefits of control response feedback. The dynamic representation was preprogrammed and as such can be considered as an open-loop simulator/

trainer method. As was noted from the separate analyses of the flight phases, the benefits of this method were most strongly apparent for the highly visual (VFR) portions of the flight. Relatively small reductions in degradation over static rehearsal were found for the instrument flight phase. Further, no crash landings were observed to occur on the first retention test for the dynamic rehearsal method group. Apparently, for this practical measure of performance, the combination of the static rehearsal package and the dynamic open-loop visual presentations were sifficient to counter degradation of those skills dependent upon the perceptual/vehicle response coordination cues.

It might be postulated, then, that the integration or coordination of far field perceptual cues, which were so well reinforced by the dynamic rehearsal method, was the critical element of the retraining. Why the dynamic display rehearsal method, without control response feedback, was consistently better than dynamic warmup practice, or even the combination of dynamic warmup and static rehearsal, is not clear. The answer may be that the pilots were able to more fully concentrate on the perceptual cues in relation to the vehicle flight and instruments during dynamic display rehearsal than when they shared the perceptual cue retraining time with the task of flying during dynamic warmup practice.

When the reinforcement of the perceptual cues was not as important (IFR portion measured at TACAN, Figure 12) or as efficiently accomplished, the addition of dynamic warmup practice eliminated degradation. The retraining methods which did not include display/control response integration were insufficient. This finding was as might be expected since no far field perceptual cues were involved and the primary task depended upon careful control response coordination.

The overall indication that dynamic rehearsal was better than warmup and that the addition of warmup to it produced negligible further improvement, suggested that the primary skill retention problem was related to the maintenance of the visual/perceptual elements of the flight control skills. Certainly manual control performance did degrade; however, with highly experienced pilots, the basic skill of integration of discrete control elements into a smooth, coordinated response, was more resistant to degradation. As such, it would appear appropriate to concentrate on enhancing the reinforcement of the understanding of the mission profile and flight operations in relation to the visual environment and perceptual cues.

The retraining method with the greatest enhancement potential and cost benefit is static rehearsal. From the standpoint of practical significance and the probability of a safe landing, it can be concluded that the dynamic rehearsal method was very successful and was equalled only by the combination of both the static rehearsal and dynamic warmup methods. Certainly some dynamic rehearsal method improvement potential existed, but it was associated with control response feedback afforded by the inclusion of dynamic practice. On the other hand, static rehearsal was shown to be as effective as limited dynamic warmup alone. While the present static rehearsal method failed to eliminate skill degradation, it was, in fact, partially successful.

One of the major failings of the static rehearsal method apparently was related to the inadequate presentation of the visual environment and critical perceptual cues. In studies of training device fidelity, Grimsley (1969a and 1969b) compared operational hardware with artist's reproductions which carefully represented the critical operational cues. For missile system procedural tasks, he found that the low fidelity equipment was equally effective as the high fidelity equipment in terms of amount of skill retained and time to retrain.

In both Grimsley's and the present problem, the integration of a critical sequence of events with the perceptual process produced the desired manual response. The timing, coordination, and control feedback are definitely more an integral part of a flight control task, but the results obtained from the dynamic rehearsal method do indicate potentially significant improvements are possible in the static rehearsal method.

Improvements in the static rehearsal can be made in three principal areas: First, more information along the flight path should be included. In this study, only eight points in the flight were depicted, three of which were under IFR conditions not requiring perceptual cue integration. More representations of altitude and line up before reaching the flare point were needed. Second, off-nominal pictorial representations should be included to permit comparisons to the normal flight profile reference, thereby giving the pilots a basis for recognizing poor performance. This approach was used for the dynamic rehearsal method and was subjectively important. Third, more active involvement with the static pictorial information is required in order to strongly establish the critical perceptual cues in the visual environment. This involvement should include: (a) prediction of future flight path from both nominal and off-nominal positions based upon visual and instrument indications of present attitude, position, and rates; (b) development, and correlation of instrument and pictorial information; and (c) definition of required corrective actions and procedural operations in appropriate time sequence.

Conclusions

The conclusions derived from the results of this study may be summarized as follows:

1. After 4 months without practice, experienced pilots encountered significant skill degradation on simulated operational flight tasks involving the use of far-field (out-the-window) visual cues.
2. Procedure task skills degraded significantly after 4 months. The degradation was less than previously found for highly practiced non-pilots, even with conditions of higher task loading. Either the dynamic display or static rehearsal prac-

tice was sufficient to reinstate procedure task performance.

3. As expected, dynamic closed-loop warmup practice, in conjunction with a carefully structured static rehearsal briefing of the vehicle and cockpit characteristics and the mission profile was highly effective in reinstating flight skills. While either static rehearsal or dynamic warmup significantly reduced the magnitude of no-practice degradation, neither practice method was able to reinstate performance by itself. Apparently each method provided skill reinforcement the other lacked.

4. Dynamic display practice, without the benefits of closed-loop warmup, totally prevented skill degradation for all portions of visual flight control. This method graphically demonstrated the substantive requirement of critical visual cue and flight operation reinforcement for skill retention training. The success of this method, and the partial success of the static rehearsal method, suggested that alternate methods of retraining which do not involve dynamic interaction may be feasible.

5. REFERENCES

1. Gardlin, G. R. and T. E. Sitterley. Degradation of Learned Skills - a Boeing and Annotated Bibliography. Boeing Document D180-15080-1. The Boeing Company, Seattle, June 1972.

2. Grimsley, D. L. Acquisition, Retention and Retraining: Effects of High and Low Fidelity in Training Devices. Human Resources Research Office, Technical Report 69-1, Feb. 1969 (a).

3. Grimsley, D. L. Acquisition, Retention and Retraining: Group Studies on Using Low Fidelity Training Devices. Human Resources Research Office. Technical Report 69-4, March 1969 (b).

4. Naylor, J. G. and G. E. Briggs. Long-Term Retention of Learned Skills: A Review of the Literature. ASD Technical Report 61-390, Behavioral Sciences Laboratory, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, August 1961.

5. Sitterley, T. E. and W. A. Berge. Degradation of Learned Skills - Effectiveness of Practice Methods on Simulated Space Flight Skill Retention. Boeing Document D180-15081-1, The Boeing Company, Seattle, July 1972.

6. APPENDIX - SUBJECT TRAINING PACKAGE

Subject Training and Retention Test Briefing

This appendix contains the materials initially presented to the test subjects at the beginning of their training and later used for rehearsal briefing. During the pretraining orientation the material was supplemented with verbal clarification during the groundschool and cockpit familiarization sessions. The pilots were permitted to refer to or study the training materials during the course of training. After completion of the training performance qualification test, no access to any of the training materials was permitted.

Prior to the retention test, written instructions were provided to the test subjects. These instructions also provided the introduction to the refresher training for Group II and III. These two groups used the same Flight Control and Procedure Training Package that was used during initial training. The retention test instructions were as follows:

Group I. No Practice - Checklist Only

Good Morning: During this next session you will complete your retention study flight testing. You have been assigned to the No Practice Group. That is, you will receive no preliminary briefings or refresher training prior to your retention flight testing. You will be seated in the simulator cockpit and the test flights will begin. At that time you will have access to two sets of checklists--(1) an approach procedures outlines; and (2) a SAS and subsystem failure procedures summary.

No questions will be answered or assistance given concerning flight procedures or techniques until completion of your flights. You will fly ten approaches to landing with the H-33 orbiter simulator from the initial approach fix, starting at altitude of 31,400 feet. These flights are similar to your qualification flights and will contain failures in the navagation instruments, displays, and flight systems that you have previously been trained to handle.

We realize that your ability to fly a precise mission has probably degraded. That is what we will be measuring. However, do the best you can. Remember that you are flying a return flight to an earth landing after a prolonged layoff. A safe, smooth flight with positive responses is desired.

This final test session will last approximately 2 hours. Are you ready?

Group II. Static Practice

Good Morning: During this next session you will complete your retention study flight testing. You have been assigned to the Static Practice Group. That is, you will have 40 minutes to study: (1) your training manual, which details the mission and tasks required; (2) a series of 8 large-scale photos showing the cockpit instruments, displays, and out-the-window views at critical points within the approach to landing; and (3) two checklists--one, an approach procedures outline, and the other, a SAS and subsystems failure procedures summary. Once you are seated in the flight simulator, you will have a few minutes to become reacquainted with the cockpit first-hand. During the cockpit review you will have access to the training manual and your checklists; during flight you will have only the checklists.

No questions will be answered or assistance given concerning flight procedures or techniques until completion of your flights. You will fly ten approaches to landing with the H-33 orbiter simulator from the initial approach fix starting at an altitude of 31,400 feet. These flights are similar to your qualification flights and will contain failures in the navigation instruments, displays, and flight systems that you have previously been trained to handle.

We realize that your ability to fly a precise mission has probably degraded. That is what we will be measuring. However, do the best you can. Remember that you are flying a return flight to an earth landing after a prolonged layoff. A safe, smooth flight with positive responses is desired.

This final test session will take approximately 2-1/2 hours including briefings and flights.

We will now proceed with the refresher training.

Group III. Dynamic Display

Good Morning: During this next session you will complete your retention study flight testing. You have been assigned to the Dynamic Display Group. That is, you will view a representative sample of three approach flights to touchdown, after reviewing your written training material. In the review, you will have 40 minutes to study: (1) your training manual, which details the missions and tasks required; (2) a series of 8 large-scale photos showing the cockpit instruments, displays, and out-the-window views at critical points within the approach to landing; and (3) two checklists--one, an approach procedures outline, and the other a SAS and subsystems failure procedures summary. Once you are seated in the flight simulator, you will have five minutes to become reacquainted with the cockpit first-hand. During the cockpit review you will have access to the training manual and your checklists; during flight, you will have only the checklists.

No questions will be answered or assistance given concerning flight procedures or techniques until completion of your flights. You will fly ten approaches to landing with the H-33 orbiter simulator from the initial approach fix starting at an altitude of 31,400 feet. These flights are similar to your qualification flights and will contain failures in the navigation instruments, displays, and flight systems that you have previously been trained to handle.

We realize that your ability to fly a precise mission has probably degraded. That is what we will be measuring. However, do the best you can. Remember that you are flying a return flight to an earth landing after a prolonged layoff. A safe, smooth flight with positive responses is desired.

This final test session will take approximately 2-3/4 hours including the briefings, retraining, and test flight.

We will now proceed with the refresher training.

FLIGHT CONTROL AND PROCEDURE

TRAINING PACKAGE

SIMULATED LANDING SPACE VEHICLE

Contract NAS9-10962

TRAINING PACKAGE

Table of Contents

INVESTIGATION OF DEGRADATION OF LEARNED SKILLS

TRAINING PACKAGE

I. INTRODUCTION

The objective of this study is to measure the degradation in performance observed in trained pilots returning after a prolonged lay-off. You have been asked to participate in this experiment because of your previous flight qualifications and your expectations not to participate in the control of an aircraft or other flight simulation for the next four months.

Your part in the study will involve: (1) study of the simulator characteristics and flight profile, (2) completion of a ground school, (3) simulator flight training, (4) a test period, (5) a 4 month period of "no flying", (6) some phase of a refresher training program, and (7) a retest.

This study has been designed to test your flight skills and performance during the approach and landing phase of a landable space vehicle. The flights will consist of normal, degraded, and emergency system operations. Your performance will be measured by our systems computer and will be judged in relation to an optimally designed flight profile.

You will be expected to participate in approximately four half-day sessions during the space of a week for the initial participation and for one period during your retest.

Our time schedule and simulator budget are limited. You are expected to train up to a nominal flight profile as quickly as possible and to fly all missions to the best of your abilities. Your instructor will be happy to answer any questions consistent with the training and our schedule limitations. Your participation in these tests is appreciated.

II. SIMULATOR/VEHICLE CHARACTERISTICS

The subject will "fly" simulator cockpit displays controlled by flight characteristics approximating those of the H-33 orbiter vehicle (Figure 2-1). The cockpit is configured with a spartan instrument panel and a simple set of controls. The vehicle attitude is controlled through an electric stick side-arm controller operating through a Stability Augmentation System (SAS). Instrumentation provides flight attitude, altitude, airspeed, and information as to vehicle position relative to radio navigation aids. An out-the-window VFR display provides a reference to touchdown on a TV terrain model of Edwards Air Force Base.

The vehicle is unpowered during its reentry and approach. A safe flight requires the judicious utilization of energy management principles and adherence to the designed flight profile.

Speed boards are provided to control the rate of descent as a function of airspeed.

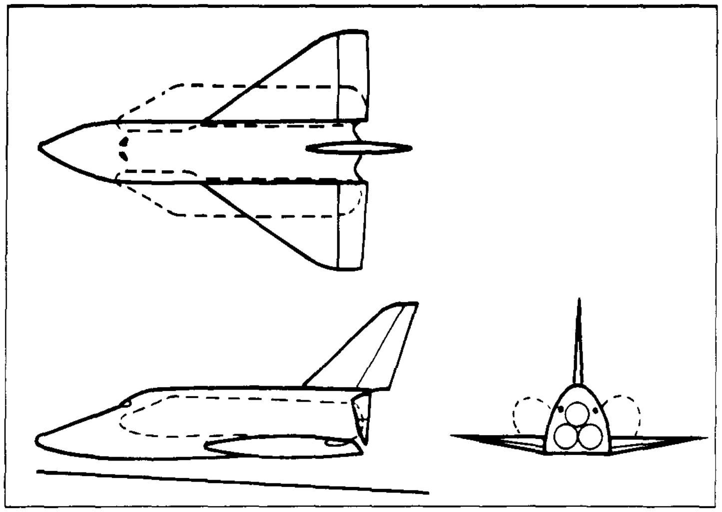
Optimum vehicle handling characteristics are obtained at an Indicated Airspeed (IAS) of 240 knots. Angle of descent, clean, is approximately 7 degrees. At 60% speed boards and 240 knots, angle of descent is 10°. A speed of 210 knots will stretch your clean glide by 20%.

III. SIMULATOR COCKPIT

A. GENERAL

The following paragraphs describe the cockpit configuration and operation of the displays and controls necessary to fly the simulated flight profile of the H-33 orbiter from 30,000 feet to landing.

The one-man cockpit is configured to provide all displays and controls necessary to fly the simulated mission. Display information is provided by both electromechanical and cathode ray tube displays. External VFR views are simulated using a virtual image system. This system provides a field of view of approximately 40 degrees through the centrally located windscreen.



		TOTAL VEH	BODY
LENGTH	FT	157	135
WIDTH	FT	95	25
HEIGHT	FT	61	27.5
LANDED WEIGHT	LB	240,000	–
FIXED SURFACES		WING	FIN
AREA EXPOSED	SQ FT	2,900	855
CHORD AT FUS	FT	68	36.7
AT TIP	FT	15.5	14.7
SWEEP -LE	DEG	55	47
TE	DEG	-5	21.8
ASPECT RATIO		1.846	1.33
TAPER RATIO		0.178	0.38
DIHEDRAL	DEG	5	–
CONTROL SURFACES		ELEVONS–TOTAL	RUDDER–TOTAL
AREA TO HINGE LINE	SQ FT	820	292
CHORD -ROOT	FT	13.6	12.8
TIP	FT	10.0	4.9
SPAN (EACH)	FT	34.8	34.8

Figure 2-1: H-33 SPACE SHUTTLE ORBITER GENERAL CHARACTERISTICS

The pilot's seat and rudder pedals are adjustable to permit the individual pilot to select a comfortable position consistent with the positioning of himself at the design eye reference point. The seat adjustments include height, fore and aft movement, back, and armrest position adjustment. The rudder pedals may be adjusted either fore or aft to compensate for seat position and leg length.

Figure 3-1 depicts the cockpit display/control layout. Directly in front of the pilot, located on the center panel, is the Electronic Attitude Director Indicator (EADI). The CRT display provides basic attitude and command information to the pilot. Directly below the EADI is the Multi-Function Display (MFD). This is a CRT display which provides a pictorial representation of the horizontal situation and ILS heading and glideslope data. To the left of the CRT displays are located an electromechanical Calibrated Airspeed Indicator and standard Radio Direction Indicator.

To the right of the CRT displays are located an electromechanical radar altitude indicator and rate of climb indicator. A master failure warning indicator is installed between these two instruments. When illuminated, this failure warning indicator directs the pilot's attention to either the Stability Augmentation Subsystem Selector Panel located on the upper left instrument panel or to the Subsystem Monitoring Panel located on the upper right instrument panel.

On the side panel to the left are located landing gear controls and indicators, as well as the simulation operation controls which cannot be seen in the figure. On the side panel to the right is the Speedbrake Indicator. Below the Speedbrake Indicator is the instrument panel light control and rudder-pedal positioning handle. The throttle and speedbrake controls are located in the front of the instrument panel to the left, and a two-axis pitch and roll sidearm controller is located in front of the instrument panel to the right. Included in the sidearm controller is the pitch trim control. A detailed description of each of the displays and controls is provided in the following paragraphs.

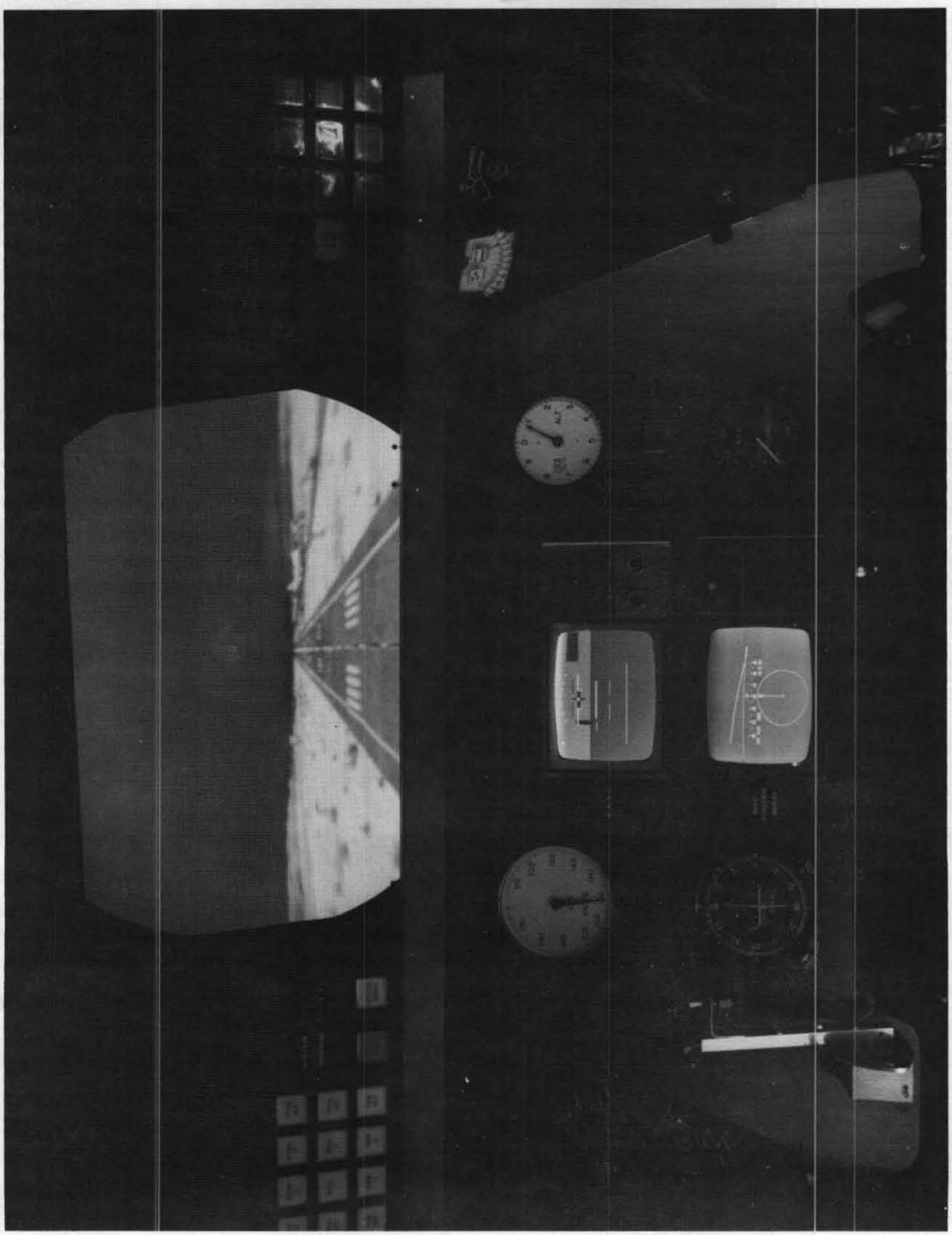


Figure 3-1: COCKPIT DISPLAY/CONTROL CONFIGURATION LAYOUT

B. INSTRUMENTS/DISPLAYS

Electronic Attitude Director Indicator (EADI)

The EADI is the primary source of attitude information and flight path command information. The EADI display format is depicted in Figure 3-2. At the top of the display on either side of the vertical white bar are three reference markers which indicate roll attitude in ten degree increments. Directly below the roll reference markers is a white aircraft symbol. The aircraft symbol and the roll reference markers remain in a fixed position on the display and are always superimposed upon other display data. Rotation of the horizon line and a perpendicular roll index bar provides roll attitude information.

Pitch reference markers are located below and above the horizon line in 10° increments. The pitch reference markers remain parallel to the horizon line regardless of rotational angle and are depicted as white lines against a shaded background below the horizon and as black lines against a light background above the horizon line. Pitch attitude information is depicted by a vertical movement of the horizon line and associated pitch reference markers in relation to the aircraft symbol. The EADI depicts the vehicle's flight path angle as a white line parallel to the horizon line and pitch reference markers. As the flight path angle changes, the flight path angle reference line (gamma) bar moves above or below the horizon line.

ILS localizer and glideslope command bars are depicted in black on the display. The localizer command bar is oriented perpendicular to the aircraft symbol; it moves laterally to the left or to the right. When a localizer bar is depicted to the left of the center of the airplane symbol, it indicates that the airplane is flying to the right of the desired heading and must be turned left to intercept the bar. The glideslope indicator bar is oriented parallel to the aircraft symbol and moves vertically. When the glideslope bar is depicted below the airplane symbol, it indicates the airplane is flying above the desired glideslope and the aircraft must be pitched down to intercept the glideslope.

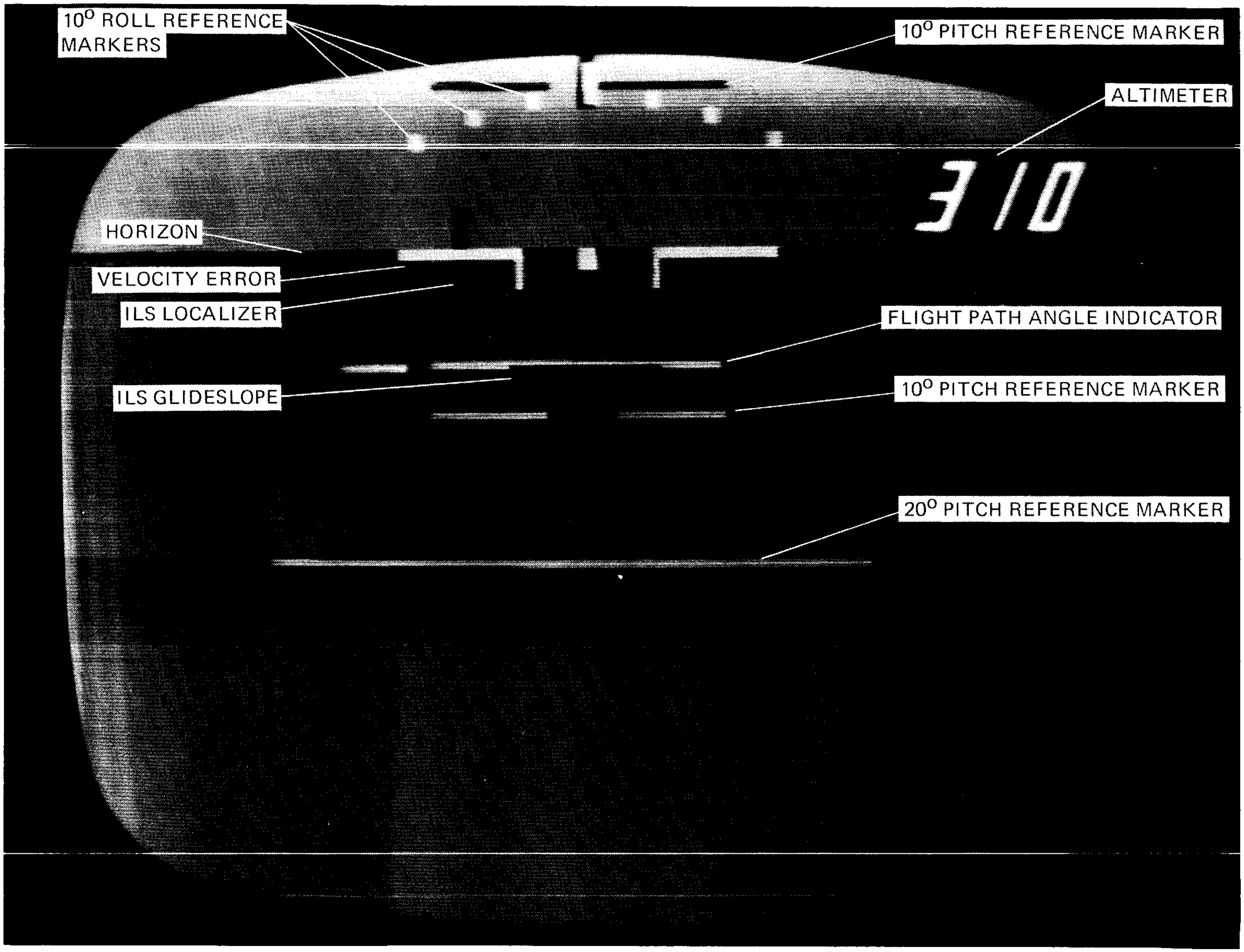


Figure 3-2: ELECTRONIC ATTITUDE DIRECTOR INDICATOR (EADI) DISPLAY FORMAT

In addition to the attitude and command information, the EADI provides altitude information in the upper right hand corner of the display. The three digit altitude information is displayed in hundreds of feet in order to provide rapid recognition during the early part of the approach when altitude varies rapidly.

Multi-Function Display (MFD)

During the approach phase of the mission, the MFD provides a digital readout of several flight instrument parameters, and a graphical horizontal situation display representing the aircraft in relation to the TACAN station and the runway. The display format of the MFD during the initial portion of the approach phase is depicted in Figure 3-3. Mach number in hundredths, equivalent airspeed to a tenth of a knot, and altitude in feet are depicted at the top of the MFD. The primary aircraft heading indicator is located directly below these digital readouts. Heading is represented dynamically by a ribbon meter with a fixed index pointer. This meter shows current aircraft heading on a two-digit degree scale which moves either to the right or to the left. When the aircraft is turned to the right, the meter scale will move to the left such that the pilot "flys to" the desired heading. Directly below the heading indicator is the TACAN course indicator depicting the heading to the TACAN station and the distance from the TACAN station.

At the bottom of the MFD is the graphical horizontal situation display. This display depicts a circle with a radius of 15 miles around the TACAN station. The TACAN is represented by a cross in the center of the circle. There is a line from the TACAN station down to the runway shown at the top of the circle. The horizontal position of the aircraft is dynamically represented with a cross. Extending from the aircraft symbol are four dots predicting the aircraft's future position. Each dot represents 10 seconds for a total 40 second prediction of the aircraft's location.

As the aircraft passes over the TACAN station, the course indicator will change from "To TACAN" to "From TACAN." At the same time the digital velocity and altitude information will be replaced by a graphical representation of the aircraft flying down the glideslope as depicted in Figure 3-4.

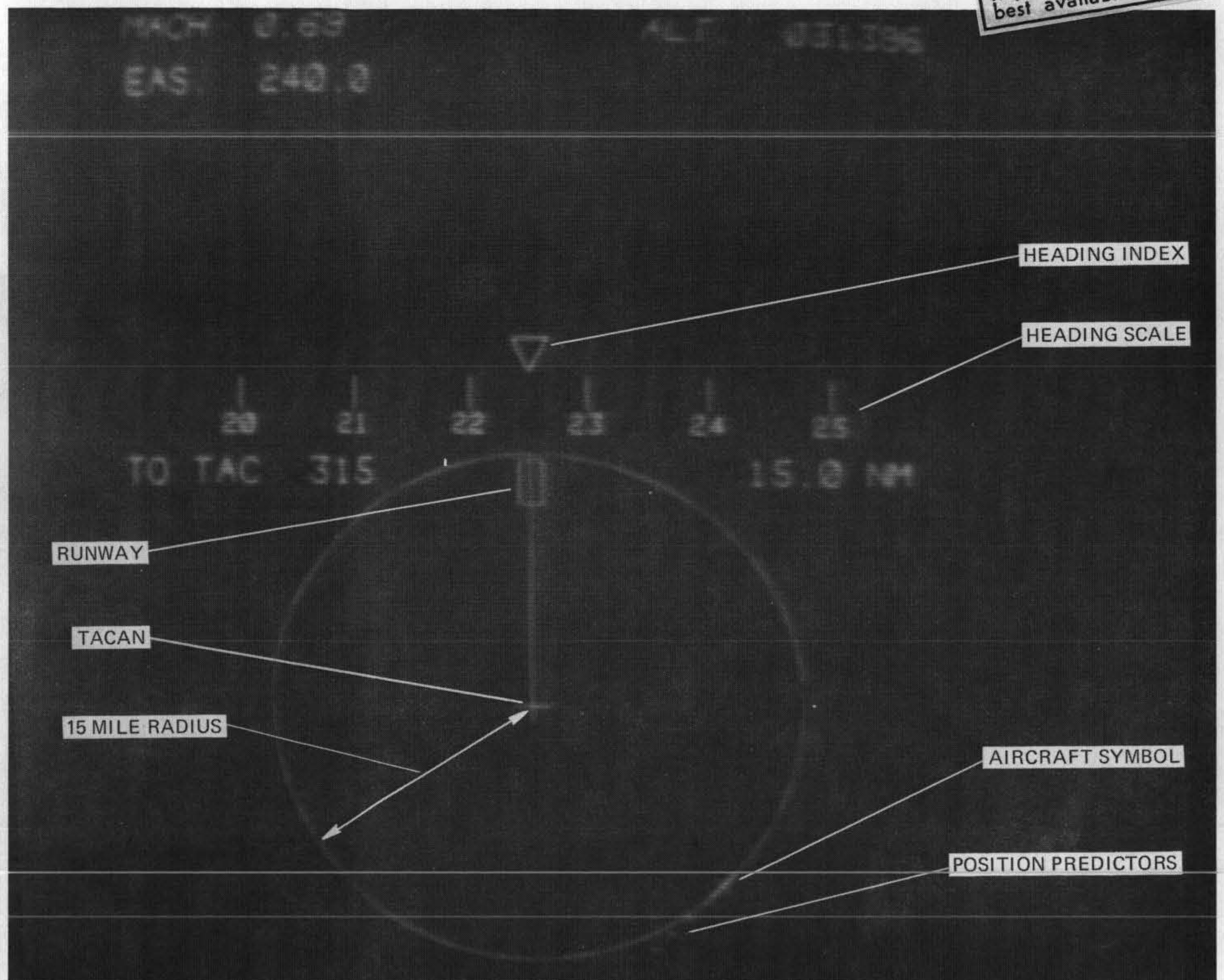


Figure 3-3: MULTIFUNCTION DISPLAY (MFD) INITIAL APPROACH PHASE DISPLAY FORMAT

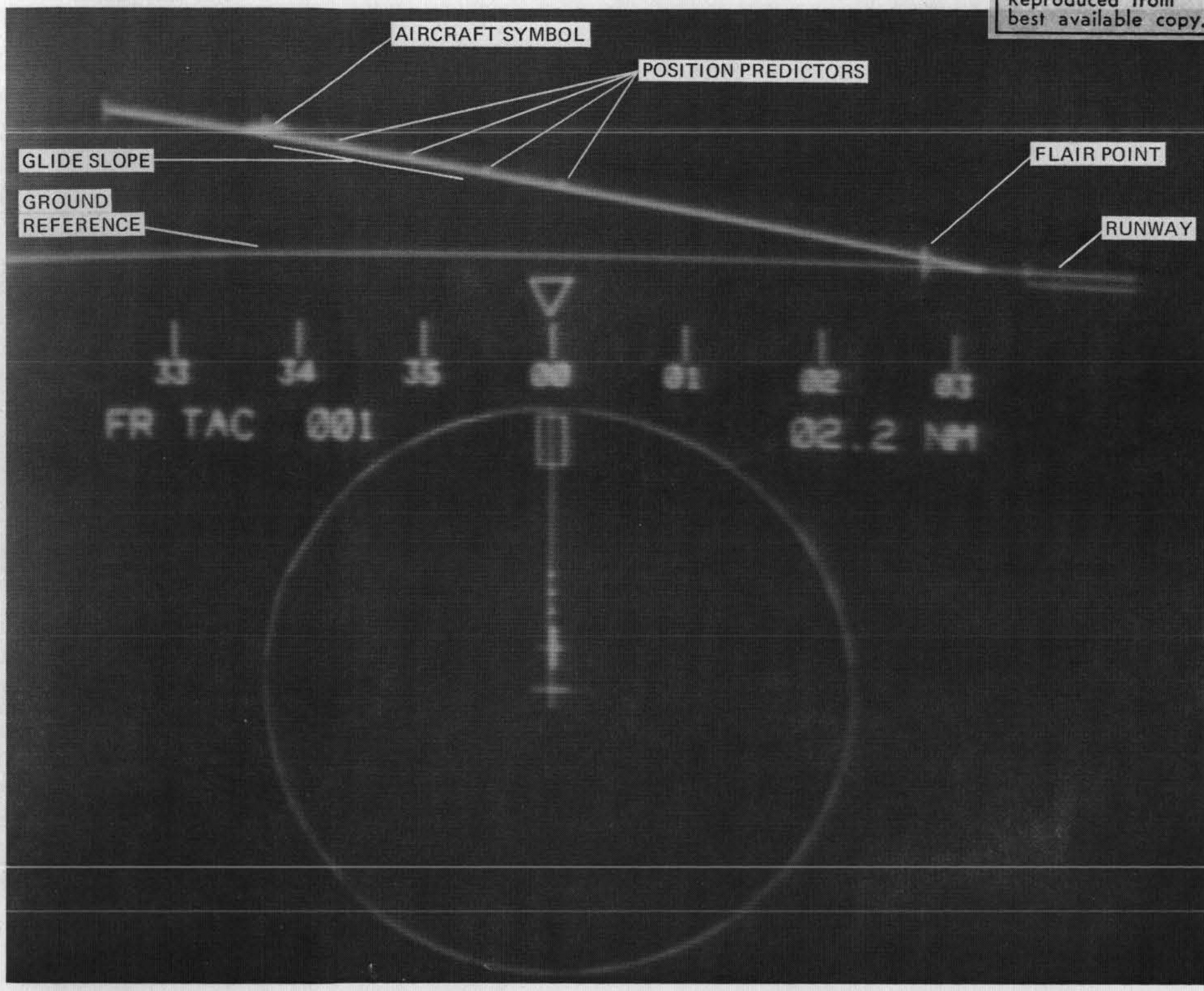


Figure 3–4: MULTIFUNCTION DISPLAY (MFD) FINAL APPROACH PHASE DISPLAY FORMAT

Once again, the aircraft position on the glideslope will be indicated by a cross with four 10-second predictor dots. A short vertical line immediately to the left of where the glideslope intersects the runway threshold indicates the nominal flare point at 750 feet of altitude.

Calibrated Airspeed (CAS) Indicator

The CAS instrument is calibrated to read airspeed from approximately 280 knots to 70 knots. The CAS is the primary velocity indicator for the approach and landing phase.

Radio Direction Indicator (RDI)

The RDI presents aircraft magnetic heading plus ILS and DME information. A digital course line can be manually selected by the pilot. As the aircraft turns, the compass card rotates. The glideslope and localizer bars indicate the centerlines of the glideslope and course line relative to the center of the instrument; thus, corrections are made by flying to an indicated offset.

Radar Altitude Indicator

The radar altimeter will not read or move dynamically above an altitude of 2,200 feet and is to be used only in the final landing phase of the flight. The altimeter pointer reads hundreds of feet to a resolution of 200 feet per increment with thousands of feet indicated digitally in the window on the altimeter face.

Rate of Climb Indicator (ROC)

The ROC is a standard electromechanical instrument displaying vertical velocities to a maximum of 2,000 feet per second. As the descent rate during the major portion of the mission exceeds the maximum capability of the meter, this instrument should be used only in the final landing phase of the flight as a backup to provide flare and touchdown rates.

Speedbrake Indicator

The speedbrake indicator is an electromechanical instrument which indicates percent of speedbrake down from 0 to 100% in 10 percent increments.

III. C. CONTROLS

Sidearm Controller

The sidearm controller, of the X-20 type, has motion in the fore and aft and lateral axes corresponding to inputs for pitch and roll, respectively. A white knurled knob for roll trim located on top of the control handle is not operational and should not be used. On the left hand side of the top of the control handle is an operational pitch trim switch. When the trim switch is pushed forward, the aircraft is trimmed nose down; when the trim switch is pulled aft, the aircraft is trimmed nose up. Trim is best accomplished by using discrete quick inputs to the trim switch with the thumb until a neutral flight control condition is obtained.

Throttle/Speedbrake

The vehicle is unpowered during the descent, approach, and landing phase of the mission; therefore, while the throttle handle may be moved it is inoperative and does not affect flight performance. A speedbrake control switch is located on the throttle control handle. It is a momentary spring-loaded switch. When the switch is displaced backwards or aft, the speedbrakes come down at a constant rate of 20% per second reducing the velocity of the aircraft by increasing drag. When the switch is pushed forward, the speedbrakes are retracted. The aerodynamic characteristics and the location of the speedbrakes on the vehicle will cause a change in pitch trim when the speedbrakes are used: the vehicle will pitch up when the speedbrakes come down and will pitch down when the speedbrakes come up. Therefore, when operating the speedbrakes the vehicle must be retrimmed in the pitch axis.

Rudder Pedals

Standard rudder pedals are located in the cockpit to provide yaw control. Depressing the right rudder pedal will yaw the aircraft to the right, and depressing the left rudder pedal will yaw the aircraft to the left.

Landing Gear

A landing gear pushbutton and two colored indicator lights provide the displays and controls necessary to operate the landing gear. When the landing gear is up, the lights are off. When the landing gear button is depressed, the red light will illuminate indicating that the gear are in transit from the "up and locked" position to the "down and locked" position. When the gear arrive in the down and locked position, the green light will indicate. It should be noted that when the landing gear doors open and the gear extend, a slight increase in drag will occur tending to reduce the velocity of the aircraft. At this time the aircraft should be retrimmed to maintain the desired velocity and flight path angle.

III. D. SIMULATION CONTROLS

The simulator operation controls are located on the left instrument panel. Three colored lights are associated with a three-position switch. When the switch is selected in the "Run" position, a green light will come on, indicating that the system is running. At the end of the mission after touchdown, the switch is selected to the reset position and a red light will come on, indicating that the simulator is resetting itself to the initial start condition. The third position is a hold position which permits the flight to be stopped at any point during the run and restarted from that point. This position should not be selected by the pilot.

IV. MISSION DESCRIPTION

A. NOMINAL FLIGHT PROFILE

You have just made a nominal de-orbit reentry pass thorugh the transition phase. You find yourself at 31,400 feet on the 135 radial, Edwards Simulated TACAN, 15 nautical miles (Figure 4-1). You are on instruments. The winds are reported calm; visibility, 15 miles. Ceiling is 10,000 feet, overcast. The cloud deck is solid through 35,000 feet.

Receive confirmation from the computer room and the model room that the system is ready. Place the simulator switch into the "Run" position; the green light should go on. Roll right; maintain 21° of bank; pitch attitude about 1° below the horizon; maintain an IAS of 240 knots. During this portion of the flight leave the speedboards up. The flight path descent angle indicated by the "gamma" bar will be about 7° down. During your initial turn in you will pass through the ILS glideslope plane. Maintain a clean configuration and your airspeed at 240 knots. As you approach the 180° radial roll out to maintain yourself on the localizer course. At this time you should be approaching the 10° glideslope. As you establish yourself on the glideslope, go to 60% speedboards and follow the glideslope command bar down, using the gamma bar to assist you. Distance and bearing information to the TACAN will be provided digitally on the MFD. Below 10,000 feet, the MFD will also present a vertical cross section of your flight profile in relation to the runway.

Should you drift off the localizer or glideslope, correct back to centerline as expeditiously as possible. Remember that the momentum of the orbiter is such that you will have to anticipate stabilization on a flight vector.

Above 6,000 feet your primary reference will probably be instruments with a cross check through the VFR display. The extension of a thin dark shadow area out from the runway indicates runway center line. Below 6,000 feet, your flight profile should be based primarily on the external VFR view with cross check on instruments. However, you should also become familiar

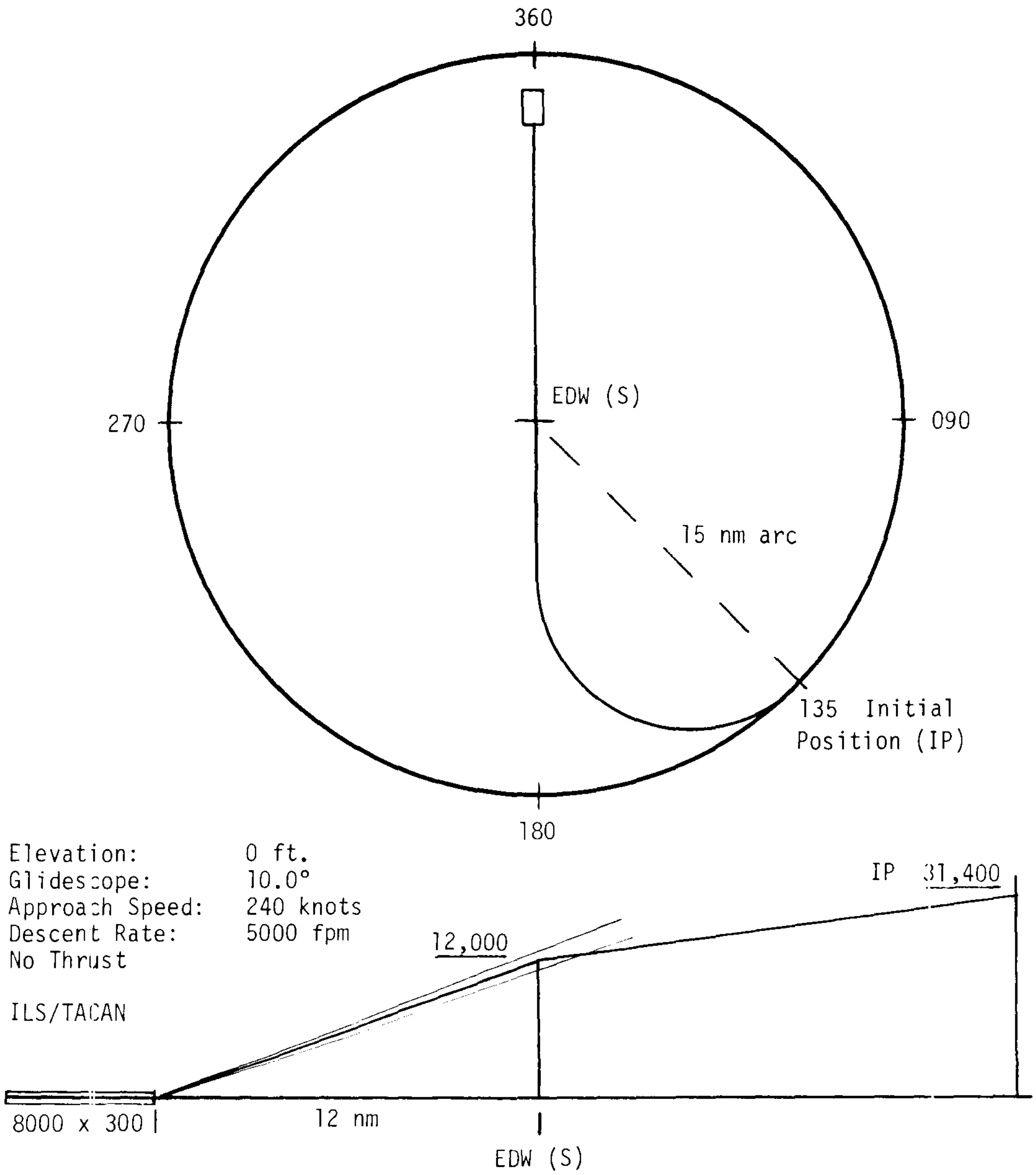


Figure 4-1: FLIGHT SCHEMATIC – EDWARDS AFB (SIM) SIMULATION APPROACH, H-33 ORBITER

with the appearance of the approach above 6,000 feet, because several approaches will be conducted with a terminal navigation failure in which the only safe reference is the VFR display.

At 2,200 feet, your radar altimeter will become operational. Use your radar altimeter to establish the 750-foot gear extension and flare point. At 750 feet, you should reduce your descent rate to follow a 3° glideslope. Use the flight-path-angle (gamma) reference bar to establish this glideslope of 3°. Hold the 3° flight path angle until you cross the threshold; at this point you should flare. Transition to a 300 fpm descent rate so as to touch down 2,000 feet down the runway. After you touchdown (indicated by the touchdown beep), return the simulation control to the RESET position and await instruction for the beginning of the next flight.

Should you experience an emergency or flight control malfunction in the flight, carry out the standard emergency procedures that you have learned in training. Remember safe control and flight of the orbiter is paramount.

IV. B. SUMMARY OF KEY FLIGHT CONTROL POINTS

1. Initial Condition

Altitude	31,400 feet
Airspeed	240 knots
Course	225 degrees
Position	135 radial, Edwards TACAN, 15 nautical miles

2. Turn-In

Set up 21° bank to the right, maintain 240 knots.

Flight path angle approximately 7°.

Pass through glideslope plane. Do not establish on the glideslope until approximately straignt-in.

3. <u>Line Up on ILS Glideslope and Localizer</u>

   a) Before TACAN: Establish yourself on the 180 radial, Course 360 to TACAN. When ILS glideslope intercepted, drop speedboards to 60%, nose down to maintain 240 knots.

   b) After TACAN: Maintain the orbiter on the ILS localizer, Course 360 from the TACAN. Establish a 10° glideslope, descent on the ILS glideslope.

4. <u>Final Approach</u>

   10° glideslope

   240 knots

   Course 360, (000)

   Cross check with VFR display below 10,000 feet

   Concentrate on VFR line up below 6,000 feet

5. <u>Flare</u>

   Altitude 750 feet

   Gear Down

   Rotate smoothly to 5° nose up

   Establish 3° glideslope

6. <u>Threshold</u>

   Altitude 200 feet

   Airspeed 180-190 knots

   Rotate smoothly to 10° nose up, establish a 1° glideslope

7. <u>Touchdown</u>

   On center line

   2,000 ft. marker

   4 to 6 fps descent rate

   Airspeed approximately 160-170 knots

IV. C. PHOTOS OF DISPLAYS AT KEY POINTS

Eight figures are presented (Figures 4-2 through 4-9) to familiarize you with the appearance of the displays at various points throughout the approach. The figures are listed below:

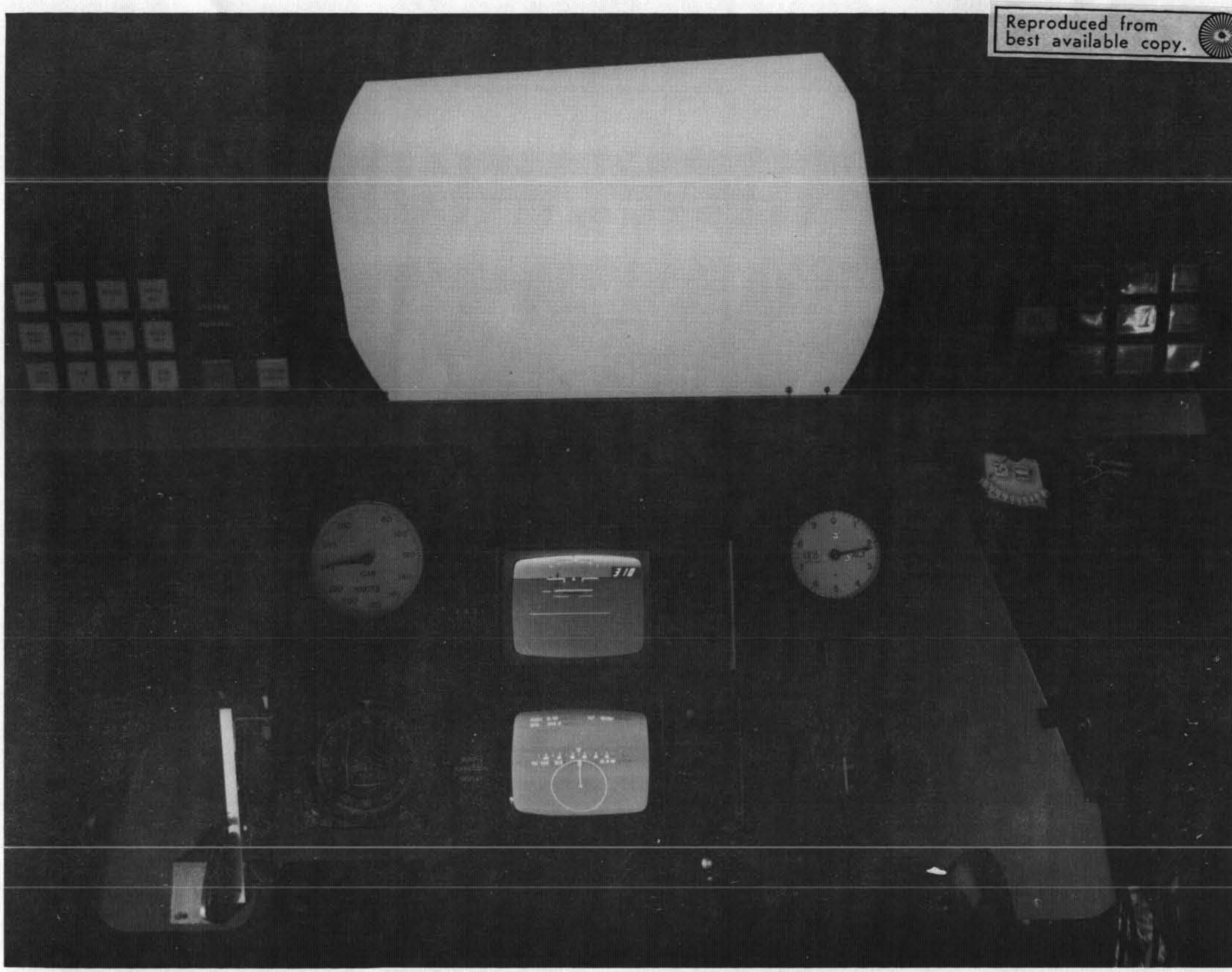


Figure 4-2: INITIAL POSITION; ALTITUDE 31,400 FEET

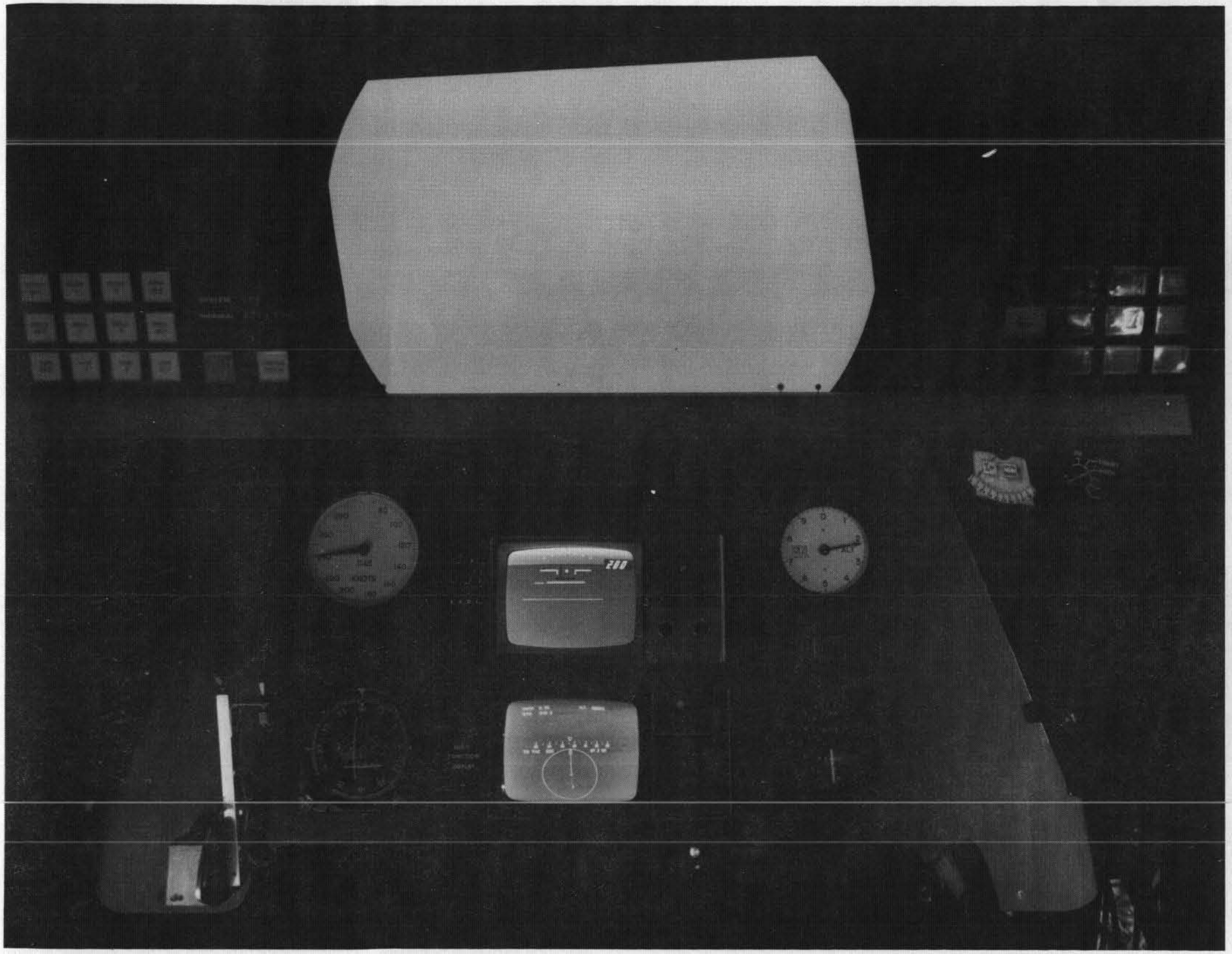


Figure 4–3: INBOUND TO TACAN: APPROACH 180^{o} RADIAL; 20,000 FT ALTITUDE

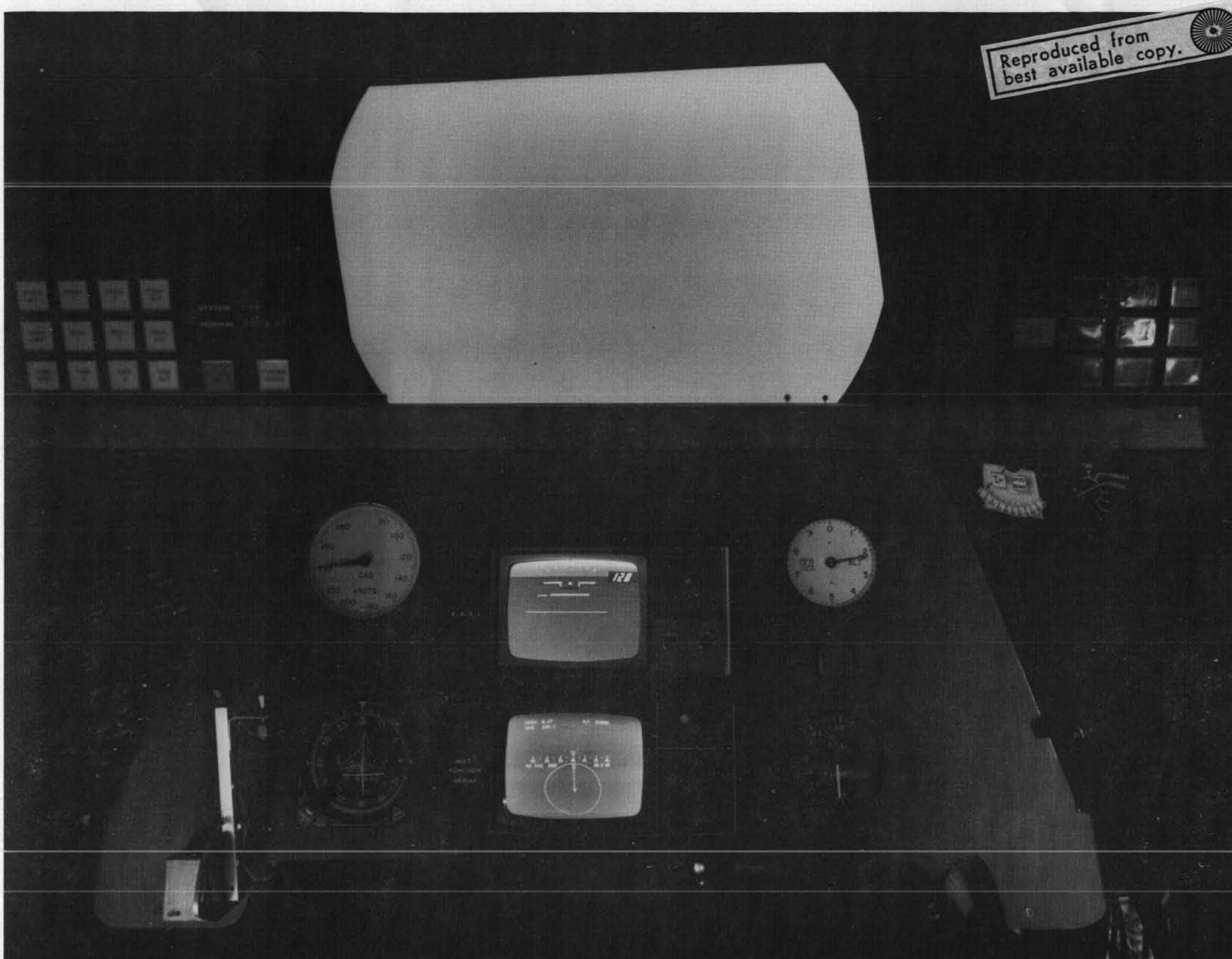


Figure 4–4: AT THE TACAN: ALTITUDE 12,000 FEET; ON COURSE, SLIGHTLY ABOVE GLIDESLOPE

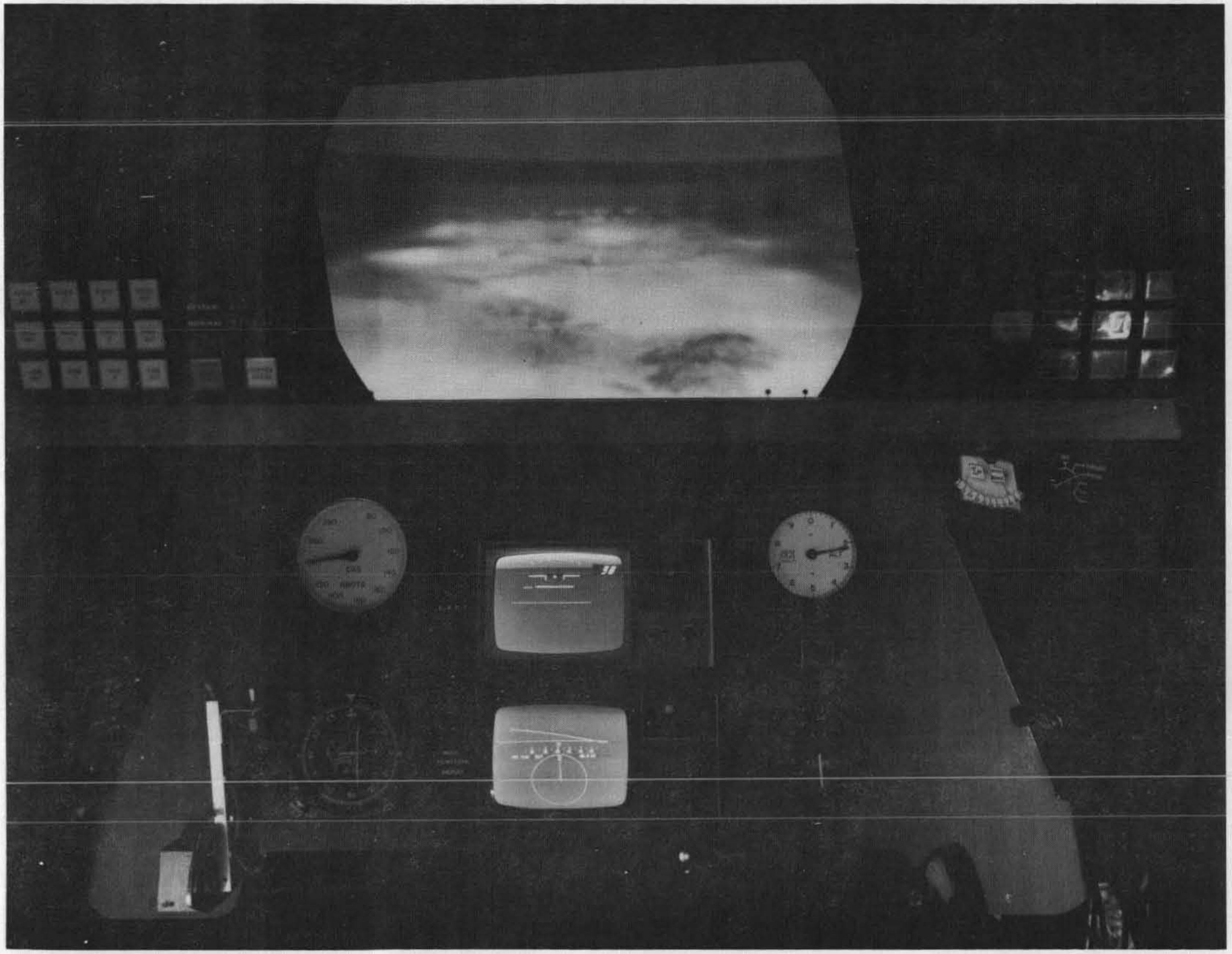


Figure 4–5: INBOUND FINAL; ALTITUDE 9,800 FEET; JUST BREAKING VFR;SLIGHTLY LEFT;ON GLIDESLOPE; SPEEDBOARD 70%

Figure 4–6: INBOUND FINAL; ALTITUDE 5,600 FEET; ON COURSE; ON GLIDESLOPE

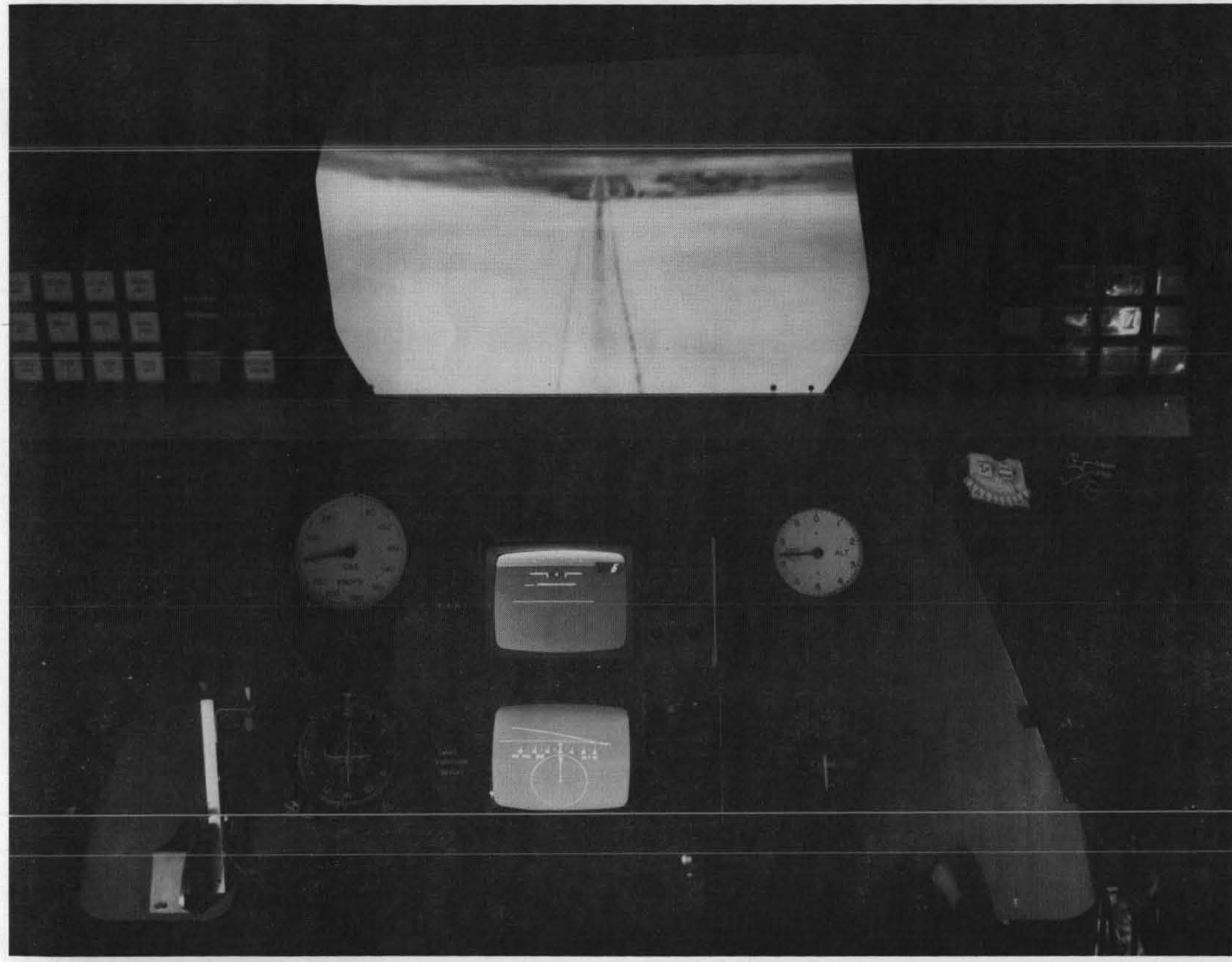


Figure 4–7: *LANDING TRANSITION; ALTITUDE 750 FEET; GEAR DOWN; FLARE TO 5^0 NOSE UP*

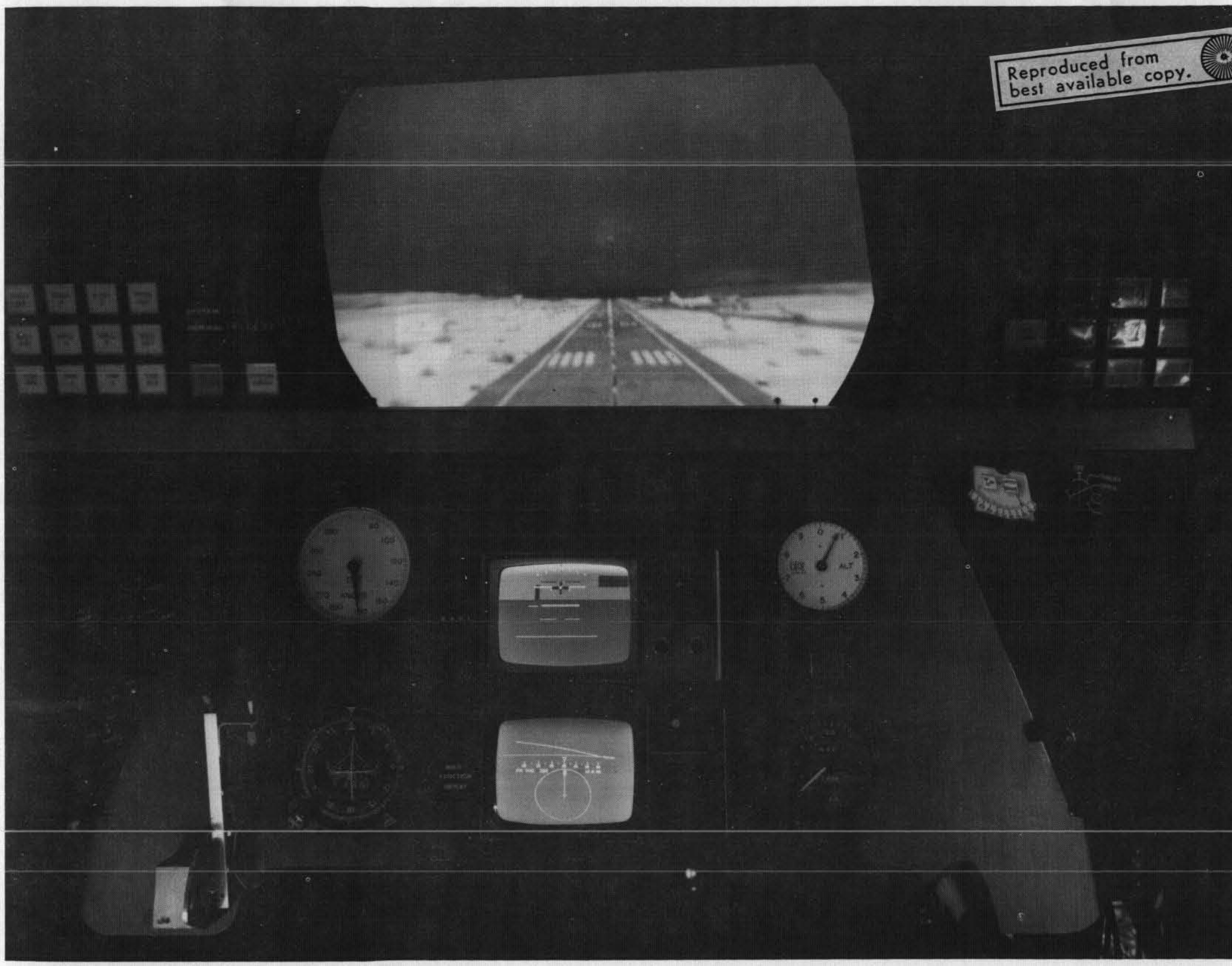


Figure 4–8: *OVER THRESHOLD; ALTITUDE 100 FEET; ROTATE*

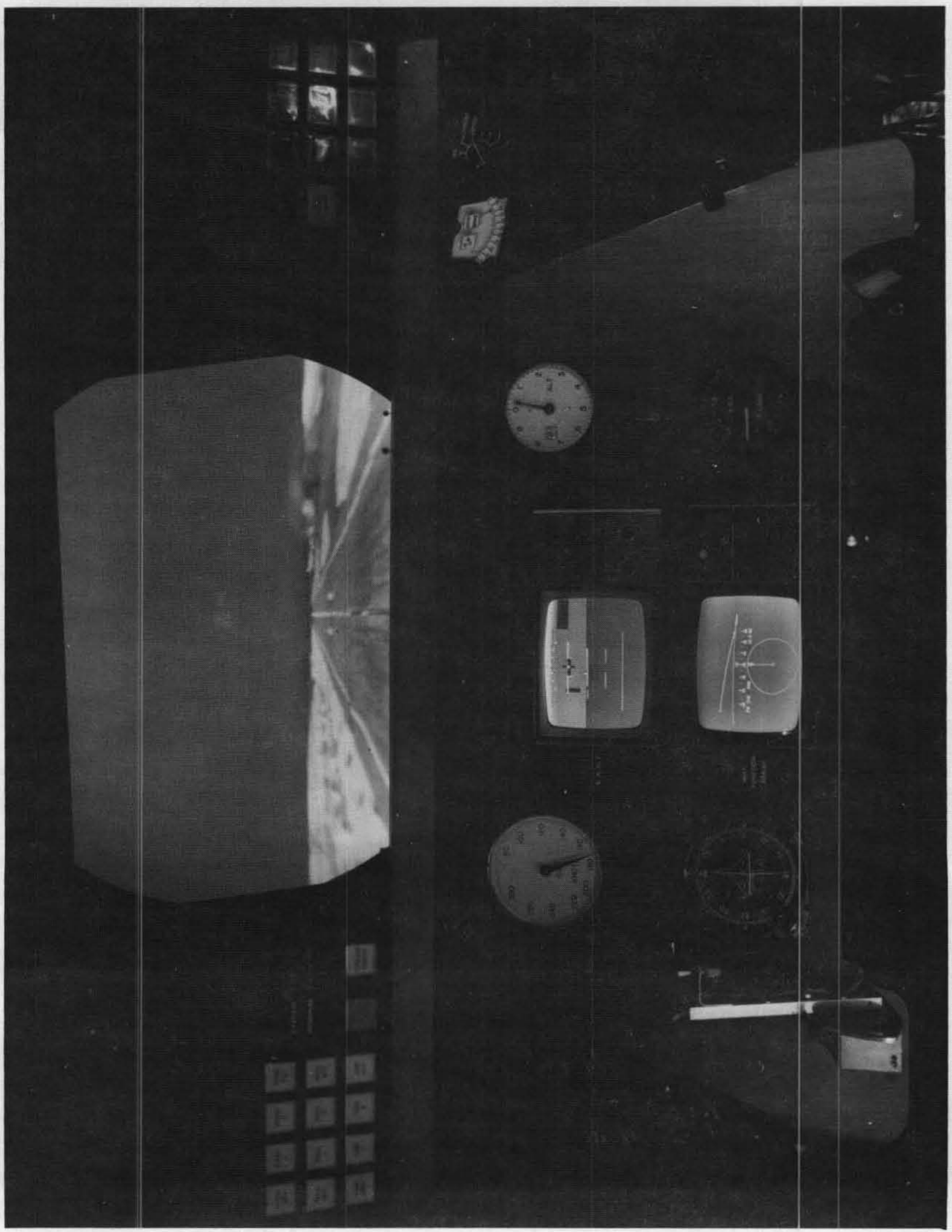


Figure 4-9: AT TOUCHDOWN; ALTITUDE 30 FEET; 200 FPM DESCENT RATE

V. EMERGENCY PROCEDURES

A. GENERAL

Emergency systems and procedures have been established for the simulator to provide more realistic subsystems management requirements during the mission and to permit the testing of flight performance during periods of stress or increased task loading.

You will be expected to learn the proper procedures to correct system failures and to handle them expeditiously. Remember, safe control of your vehicle is most important; correct, rather than hasty, actuation of system switches is essential. However, you will be tested on the speed as well as the correctness of your responses, so a concentrated subsystems training program will be required.

B. COMPLETE SUBSYSTEMS SCAN

The major subsystems of the vehicle are constantly monitored for normal operation by a Master Caution and Advisory system. When a failure is detected by the system, the master failure warning light will illuminate and the onboard system computer will identify the suspect system by illuminating a legend on the Subsystem Monitoring Panels (Fig. 5-1). The master warning light will remain illuminated until the pilot acknowledges the failure by depressing the Subsystem Failure Switch Light on the subsystem Failure Advisory Panel, or selecting a secondary SAS subsystem on the Stability Augmentation System (SAS) Monitor and Control Panel.

A computer-controlled troubleshooting system is also provided. When properly actuated, this system starts a computer scan that attempts to isolate the faulty component or network and reroute the signals and/or make use of alternate supply sources. This scan normally takes approximately 15 seconds. The system is started by depressing the identified system switch light (identified by its flashing light) and then depressing the Fail-Scan switch. Both switches will light steady during the scan. At completion, the Fail-Scan light will go out. If the faulty subsystem can be corrected, the failure information light will also go out. If no correction is possible, the subsystem failure light will remain on.

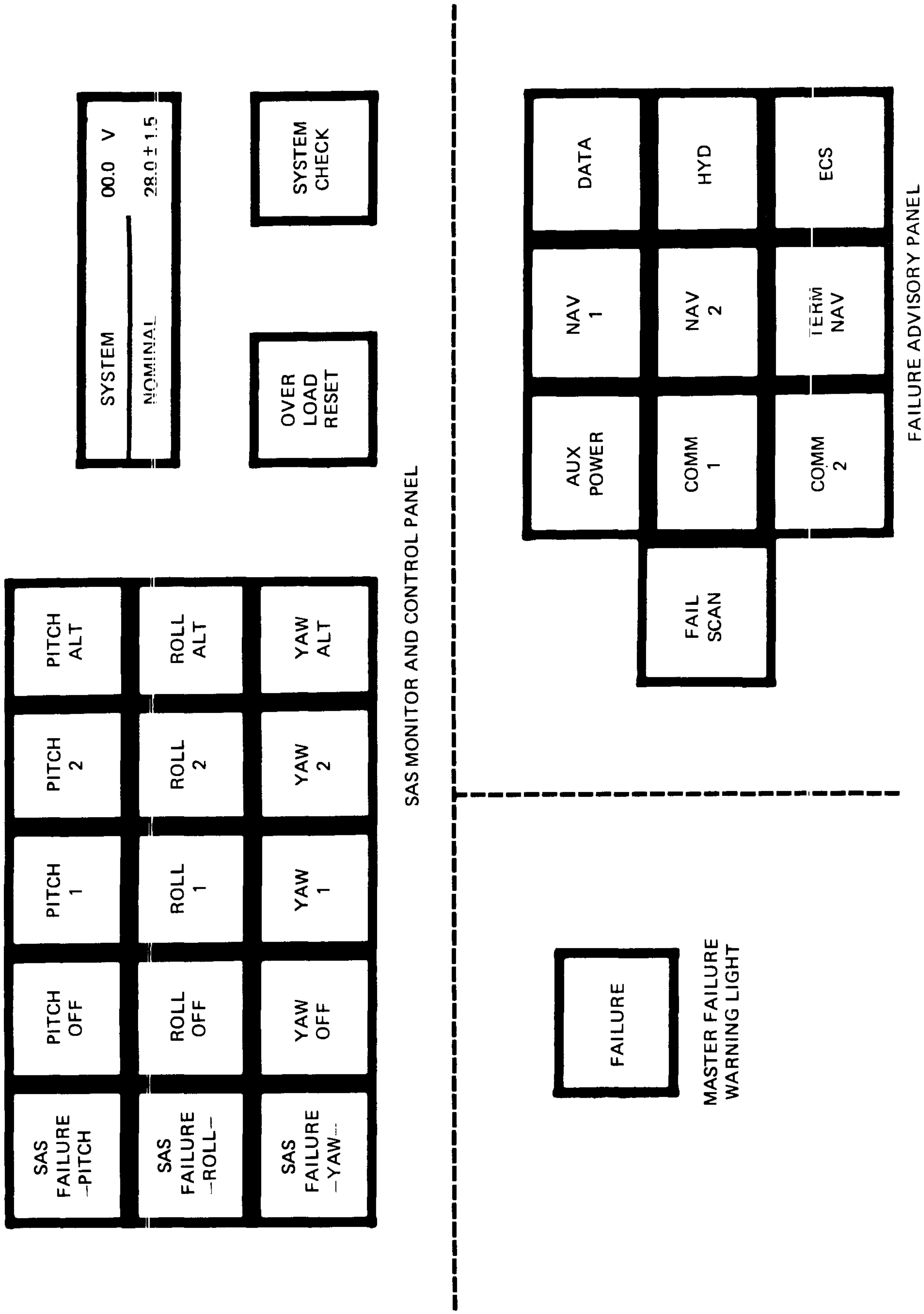


Figure 5-1: SUBSYSTEM MONITORING PANELS

C. STABILITY AUGMENTATION SYSTEM (SAS)

The H-33 orbiter simulator is fully aerodynamic and includes a stability augmentation system (SAS) in all three axes--pitch, roll, and yaw. A Selector panel in the cockpit permits manual deactivation or alternate mode switching for any or all of the axes.

The SAS system has three redundant sensor/signal comparing modules for each axis: SAS 1, SAS 2, and SAS Alternate. Each module is divided into redundant primary and secondary control units, composed of sensors and signal conditioning equipment, which produce control signals dependent upon vehicle performance, environmental conditions, and pilot input. The outputs of the primary and secondary control units are balanced by a comparator which then transmits summed control signals to the flight control system. A failure is sensed and indicated if either control unit operating voltage is out of tolerance.

Each of the SAS control units operates under a normal system voltage of 28 $\pm$ 1.5 vdc. If the SAS Failure light illuminates, it indicates that primary or secondary unit supply voltage exceeds these normal limits or that an internal failure of a system component has occurred. If a failure occurs, the next SAS system in line should be selected and the operating voltages of the selected mode checked twice--once for the primary unit and once for the secondary unit. The normal mode progression sequence for SAS operations is: (1) SAS, (2) SAS 2, (3) SAS Alt, and (4) SAS Off.

The SAS system is not completely self switching. All the mode (SAS 1, SAS 2, SAS Alt, SAS Off) switching, and the primary and secondary unit operating voltage checks must be initiated manually. When performing the unit voltage checks, however, the digital voltmeter is automatically sequenced from the primary to the secondary unit. If more than two voltage checks are made for any one mode, or a SAS mode is selected out of sequence, an overload light will illuminate. The system must be reset, and voltage checking restarted on the SAS 2 mode.

A logic diagram of the procedures for a SAS Pitch failure is presented in Figure 5-2. The logic is the same for roll and yaw failures. A SAS failure procedures check-off list is presented in Table 5-1.

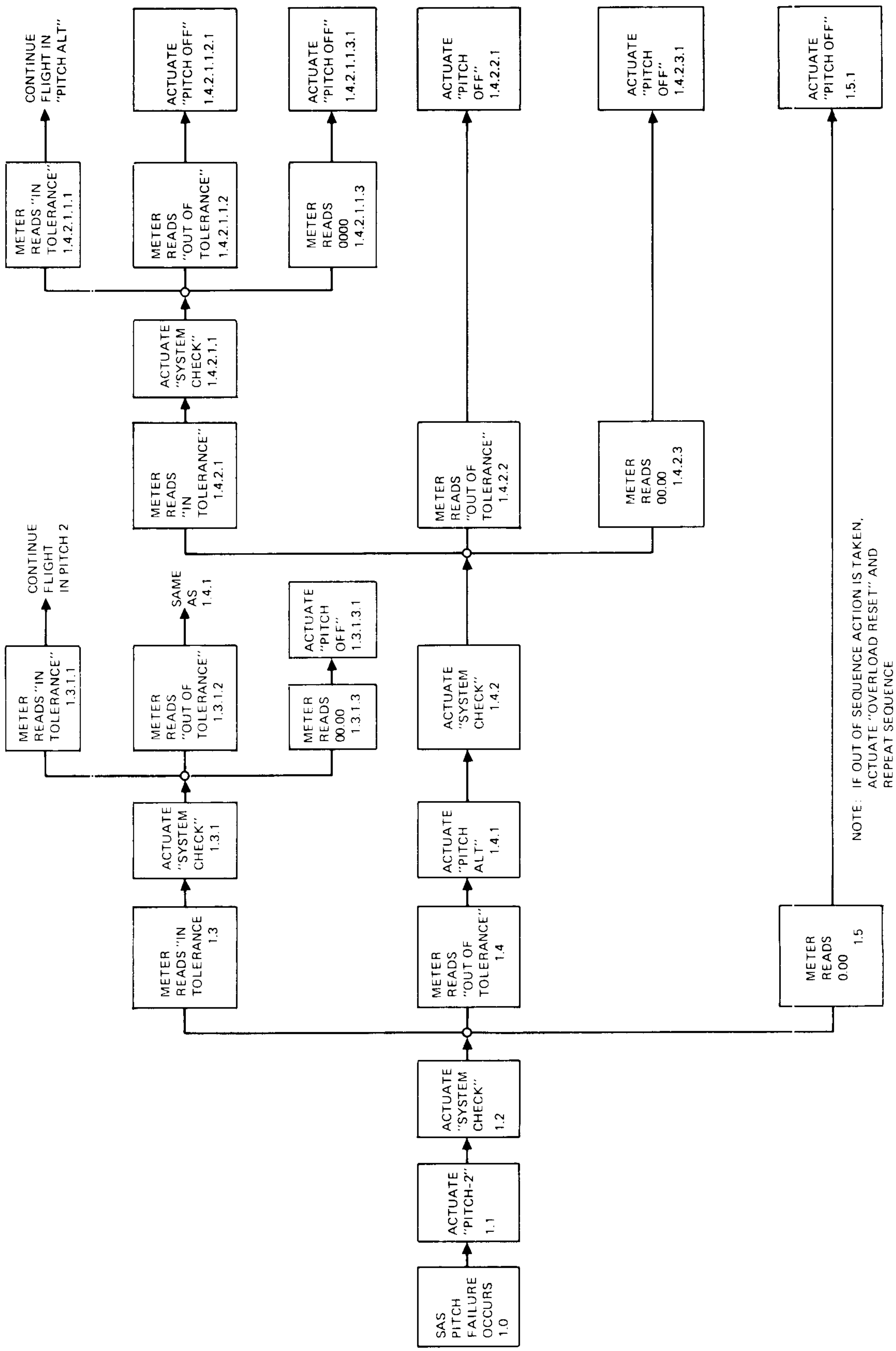


Figure 5-2: SAS PITCH FAILURE PROCEDURE CONTROL LOGIC DIAGRAM

TABLE 5-1. SAS FAILURE PROCEDURES CHECK LIST

1. Failure Occurs (Pitch mode chosen as example)

   a) "Master Failure" lights blinks.
   b) "SAS Fail-Pitch" light blinks.
   c) "Pitch-1" light blinks.

2. Push "Pitch-2"

   a) "Master Failure" light goes out.
   b) "SAS Fail-Pitch" light stops blinking (remains on).
   c) "Pitch-1" goes out.
   d) "Pitch-2" goes on.

3. Push and hold in "System Check" switch.

   a) Optimum system value plus tolerance limits appear in lower meter window.
   b) System value appears in upper meter window:
      1) If meter reads within tolerance, release and re-depress switch to check the secondary system. If secondary is also normal, continue flight in selected mode (i.e., Pitch-2).
      2) If meter reads to high or too low (out of tolerance) at any point in the check sequence, immediately go to the next SAS mode (i.e., Alternate) in the system, recheck, and continue.
      3) If meter reads zero at any point in the check, immediately go to system off - (i.e., "Pitch Off"; flight continues with pitch SAS inoperative.)

4. If overload reset light comes on, push Overload Reset switch. This resets system to Mode-2, ready for voltage checks; continue.

<u>Summary</u>: Flight normally begins in Pitch-1. If system malfuncitons, Pitch-2 is selected. If Pitch-2 is out of tolerance (other than zero), Pitch-Alternate is selected. If Pitch-Alternate is out, Pitch-Off is selected.